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Submitted by : BAHALLAH Meriem DJIR Takwa

Theme

Medium Access Control in WSN Network for water management system

Jury members :

Mr.	BENDOUMA Taher	MC(A)	(University of Laghouat)	President
Ms.	BENKOUIDER Sara	MC(A)	(University of Laghouat)	Examiner
Mr.	KERRACHE Chaker Abdelaziz	MC(A)	(University of Laghouat)	Examiner
Mr.	Lakhdar OULAD DJEDID	MC(A)	(University of Laghouat)	Advisor

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جـامعة عمار ثـليجي بالأغـواط
Université Ammar Telidji Laghouat

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Faculté des Sciences
قـسـم الإعـلام الآلـي
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Présenté par : BAHALLAH Meriem DJIR Takwa

Thème

Contrôle d'accès physique dans le réseau WSN pour le système de gestion de l'eau

Membres du jury :

Mr.	BENDOUMA Taher	MC(A)	(Université de Laghouat)	President
Mlle.	BENKOUIDER Sara	MC(A)	(Université de Laghouat)	Examinateur
Mr.	KERRACHE Chaker Abdelaziz	MC(A)	(Université de Laghouat)	Examinateur
Mr.	Lakhdar OULAD DJEDID	MC(A)	(Université de Laghouat)	Encadreur

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بسم الله الرحمن الرحيم

Dedication

I dedicate this modest work to my dear parents. To my very dear and tender mother, who supports me to this day, and to whom I can never express enough my love and absolute respect. May God protect her for us.

To my dear father, who has always filled my paths with strength and light.

To my dear brothers, for their love and support.

To my dear friends, for keeping very beautiful memories with me during these five years, and other friends.

To all the teachers, who encouraged me and have been an example for me.

DJIR Takwa

Dedication

With heartfelt gratitude and profound appreciation,

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DJIR Takwa and BAHALLAH Meriem,
June 2023

Medium Access Control in WSN Network for water management system

Abstract: Nowadays, wireless sensor networks (WSNs) are widely used for collecting and disseminating data from sensor nodes to centralized systems. In this context, a corporation like the Algerian Water Corporation (ADE), which relies on manual methods, faces significant limitations, including inefficiency and the inability to promptly detect and respond to issues. Through the employment of different sensors and transmission modules, WSNs enhance water management activities, including the quality and quantity of water. Despite these benefits, WSNs face problems such as network congestion and the critical need for effective Medium Access Control (MAC) protocols. These protocols are important for maintaining the efficiency of the network, controlling collisions, and prolonging the network's operational lifespan. WSNs have several nodes that produce different data with different transmission rates and urgency, hence creating congestion and unnecessarily high collisions. An effective (MAC) protocol provides equal access to the channel and improves energy consumption as well as throughput. To address these problems, therefore, this dissertation proposes a new (MAC) protocol. The performance of the proposed protocol is analyzed thoroughly and extensively through simulation using the NS2 simulator. The protocol demonstrates higher performance in terms of reducing collisions, improving scalability, and achieving higher throughput compared to existing protocols. Hence, this work provides a significant improvement in WSN communication protocols because it presents a reliable solution for water management systems; at the same time, it establishes a basis for future research in the field.

Keywords : WSN, MAC, ADE, NS2.

التحكم في الوصول الى الوسائط في شبكة أجهزة الاستشعار اللاسلكية لنظام إدارة المياه

ملخص: في الوقت الحاضر، تُستخدم شبكات الاستشعار اللاسلكية (WSNs) على نطاق واسع لجمع ونشر البيانات من عقد الاستشعار إلى الأنظمة المركزية. وفي هذا السياق، فإن مؤسسة مثل الجزائرية للمياه (ADE) التي تعتمد على الأساليب اليدوية، تواجه عوائق وقيوداً كبيرة. بما في ذلك عدم الكفاءة وعدم القدرة على اكتشاف المشاكل والاستجابة لها بسرعة. من خلال استخدام أجهزة استشعار ووحدات نقل مختلفة، تعمل شبكات WSNs على تعزيز أنشطة إدارة المياه، مركزة على جودتها وكميتها. على الرغم من هذه الفوائد، تواجه شبكات WSNs مشاكل مثل ازدحام الشبكة والحاجة الماسة لبروتوكولات فعالة للتحكم في الوسائط (MAC)، إذ تعتبر هذه البروتوكولات مهمة للحفاظ على كفاءة الشبكة، والتحكم في الاصطدامات، وإطالة العمر التشغيلي للشبكة. تحتوي شبكات WSNs على العديد من العقد التي تنتج بيانات مختلفة بمعدلات نقل مختلفة، وبالتالي الزحام يخلق أضراراً، واصطدامات عالية غير ضرورية.بينما يوفر بروتوكول (MAC الفعال وصولاً متساوياً إلى القناة ويحسن استخدام الطاقة والإنتاجية. إذا ومعالجة هذه المشاكل، تقترح هذه الأطروحة بروتوكول (MAC)جديد. يتم تحليل أداء البروتوكول المقترح بدقة وعلى نطاق واسع من خلال المحاكاة باستخدام جهاز المحاكاة NS2. يقدم تحليلنا حلولاً جديدة لتقليل الاصطدامات وتحسين قابلية التوسع وتحقيق أداء مقارنة بالبروتوكولات الحالية.بالتالي يوفر الحل المقترح نظاماً متكاملاً لنظام WSNلأنه يقدم حلاً موثوقاً لأنظمة إدارة المياه، فإنه يضع أساساً للبحث المستقبلي في هذا المجال.

الكلمات المفتاحية : WSN، MAC، ADE، NS2.

Contrôle d'accès physique dans le réseau WSN pour le système de gestion de l'eau

Résumé : De nos jours, les réseaux de capteurs sans fil (WSN) sont largement utilisés pour collecter et diffuser des données depuis des nœuds de capteurs vers des systèmes centralisés. Dans ce contexte, une société comme la Société algérienne des eaux (ADE), qui s'appuie sur des méthodes manuelles, se heurte à des limites importantes, notamment l'inefficacité et l'incapacité à détecter et à répondre rapidement aux problèmes. Grâce à l'utilisation de différents capteurs et modules de transmission, les WSNs améliorent les activités de gestion de l'eau, notamment la qualité et la quantité de l'eau. Malgré ces avantages, les WSNs sont confrontés à des problèmes tels que la congestion du réseau et le besoin critique de protocoles efficaces de contrôle d'accès au support (MAC). Ces protocoles sont importants pour maintenir l'efficacité du réseau, contrôler les collisions et prolonger la durée de vie opérationnelle du réseau. Les WSNs comportent plusieurs nœuds qui produisent des données différentes avec des taux de transmission et une urgence différents, créant ainsi une congestion et des collisions inutilement élevées. Le protocole MAC efficace offre un accès égal au canal et améliore l'utilisation de l'énergie ainsi que le débit. Pour résoudre ces problèmes, cette thèse propose donc un nouveau protocole MAC. Les performances du protocole proposé sont analysées de manière approfondie par simulation à l'aide du simulateur NS2. Le protocole démontre des performances supérieures en termes de réduction des collisions, d'amélioration de l'évolutivité et d'obtention d'un débit plus élevé par rapport aux protocoles existants. Par conséquent, ce travail apporte une amélioration significative des protocoles de communication WSN, car il présente une solution fiable pour les systèmes de gestion de l'eau ; en même temps, il établit une base pour les recherches futures dans le domaine.

Mots Clés : WSN, MAC, ADE, NS2.

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List of Acronyms

FDMA Frequency-Division Multiple Access. 35, 36

FFT Fast Fourier Transform. 35

FSP Flow Setup Packet. 43

FSPs Flow Setup Packets. 43

GSM Global System for Mobile Communication. 3

IEEE 802.11. Institute of Electrical and Electronics Engineers 802.11. 38

IEEE 802.15. Institute of Electrical and Electronics Engineers 802.15.. 26

IEEE 802.15.4 Institute of Electrical and Electronics Engineers 802.15.4. 27–29, 64–66, 69, 72, 75

IoT Internet of Things. 4, 12, 14, 26, 33, 82

ISM Industrial, Scientific and Medical. 28

iwsns Industrial Wireless Networks. 18

LoRaWAN Long Range Wide Area Network. 30, 32

LPWAN Low-Power Wide-Area Network. 30

LR-WPANs low-rate wireless personal area networks. 72

MAC Medium access control. iv, vi, 3, 4, 21, 24, 26–28, 30–34, 36, 37, 39, 42, 45, 50, 52–54, 57, 58, 60–67, 69, 72, 74–76, 78–82

MCU Microcontroller Unit. 30

NAV Network Allocation Vector. 43

NRT-MAC Novel Real-Time MAC. x, 41, 42

NS2 Network Simulator 2. 64, 80, 81

OFDM Orthogonal Frequency-Division Multiplexing. 35, 72

OFDMA orthogonal frequency-division multiple access. 35

OSI Open Systems Interconnection. 19, 20

OWC Optical Wireless Communications. 26

PHY Physical Layer. 26–28

PR-MAC Path Oriented Real-time MAC. 41

RAT Reserved Active Time. 42

RTS request to send. 38–40, 42, 43, 55

S-ALOHA Slotted ALOHA. 64, 65, 67, 72, 76–81

S-MAC Sensor MAC. 39–42, 45

SCH Scheduling Frame. 38, 43

SFs Spreading Factors. 30

SIFS Short Interframe Space. 38

STT Start of Transmission Times. 65, 67–69, 76, 78, 79

SYNC synchronous. 37, 39, 40

SYNCRTS synchronous request to send. 39

TDMA Time Division Multiple Access. 24, 35, 36, 41, 51, 52, 54, 56–58, 62, 66

THC Total Highway Capacity. 75, 77

TSR Time Slot Reservation. 51

Vslot virtual slot. 66, 67

W-MAC WAVE-MAC. 40, 41

WBAN Wireless Body Area Network. 27

WPAN Wireless Personal Area Network. 26

WPANs Wireless Personal Area Networks. 26, 27

WSN Wireless Sensor Network. iv, vi, 4, 13–15, 19, 20, 24, 30, 32–34, 36, 49, 57, 81

WSNs Wireless Sensor Networks. iv, vi, 3–5, 11, 14, 15, 17–19, 26, 31–36, 39–42, 44, 54, 56, 58–60, 62, 63, 82

Chapter 1

Introduction

1.1 Motivation

The Algerian water corporation, known as ADE, manages water distribution and consumption in urban areas comprehensively, covering both quantitative and qualitative aspects. The water production process involves using submersible pumps to draw water from shallow and deep boreholes, ensuring a continuous supply. The amount of water extracted is determined by various factors, including aquifer depth, pumping rate, and distance to the reservoir, ensuring that the well does not run dry and that excessive pressure cycles are avoided. Monitoring, treating, and maintaining the infrastructure systems are crucial for ensuring water quality and reliability. Treatment processes include primary treatment to remove debris, filtration to reduce turbidity, disinfection to eliminate bacteria, and desalination for areas with high salinity. Frequent testing and monitoring ensure that the water meets safety standards and complies with regulations.

Underground pipelines are used for water distribution in cities, forming a network structure that ensures a consistent water supply to all major parts of the city. These canals act as the main arteries of the water supply network, reaching even the smallest villages. Optimal water pressure is pre-set, with stricter standards for higher pressure levels. Pressure is a key determinant of the amount and quality of water received by end-users. During delivery, minor refinements may be made to maintain safe chlorine levels. ADE's water management system emphasizes public health and safety by providing clean and safe water.

The reliance on manual processes in the traditional system, including various issues leading to service disruptions, poses the biggest challenge for ADE. Manual intervention often involves numerous human elements, which can become obstacles to delivering water to consumers. Delays, inefficiencies, and human errors disrupt service reliability, as the operation is managed manually, lacking real-time monitoring and process automation. Consequently, the sustainability of the water supply, in terms of both quality standards and timely delivery, is at risk.

The advent of wireless sensor networks (WSNs) introduces innovative solutions to these challenges. WSNs mitigate the drawbacks of traditional water management systems by incorporating sensors that measure various indicators, enabling autonomous and precise water management. Integration of sensor networks with GSM modules enhances mobility and accessibility, allowing remote observation and management. The growing consumption rate and the need for congestion alleviation highlight the relevance of advanced technologies for smart resource utilization [6].

1.2 Problem statement

Data transmission requires an efficient communication mechanism to avoid data loss, With the widespread use of applications that rely on wireless sensor networks, different types of generated data have different characteristics, such as transmission rate, packet loss, priority, and data volume [5].

Similarly, in water management systems, information about water quality, quantity, and distribution faces challenges related to accuracy, real-time monitoring, and infrastructure limitations. These systems often struggle with issues such as data transmission delays, loss of critical information and high rate of traffic congestion in the network which increase the collision risk in the medium. this situation affect the application performance in terme of fairness, convergence time, and efficiency.

In many applications, WSNs are required to operate for several years without human intervention. However, sensor nodes are energy constraint. Nodes in a sensor network start to become disconnected, once the energy of sensor nodes drains out, resulting in performance degradation of the network. Therefore, prolonging the lifetime of the network is crucial for network performance [5].

In other wise, The nodes of wireless sensor networks are generally no mobile, and the network topology is not fixed due to the reduced life of the nodes, so the communication network protocols need to self-adapt to the topology changes ; the software upgrades are time consuming due to the large number of sensor nodes [7].

MAC (Medium Access Control) protocols have a significant impact on congestion avoidance and energy consumption of sensors, its role is to decide how nodes get an exclusive access to the shared medium and to ensure that only one node access the channel at a time. so that collisions can be reduced with efficient design of MAC protocols to maintains higher throughput and lower latency.

1.3 Objective

This dissertation aims at filling the gap and proposing the rightful MAC protocols that can be reliably used on Wireless Sensor Networks (WSN) in water management by ADE. The entry point is the recognition of intricacies in the existing MAC protocols, as the main focus of the work will cover both static and random access methodologies.

The research tends to do an analysis using a systematic way of comparing the MAC protocols's strengths and weaknesses against different operational conditions in order to make a holistic assessment of their performance. The outcome is to make optimal MAC protocols for WSNs that are based on getting rid of the issues linked to network congestion, and scalability.

In this light, the dissertation objective is to shine the spotlight on the issue in focus so as to enlighten the researchers and the practitioners, ultimately guiding them to build and use the future versions of the MAC protocols that will be more effective on WSNs, which are usually dynamic and complex.

1.4 dissertation organization

The organization of this dissertation is structured as follows :

- **Chapter two**(2) provides an in-depth exploration of water management systems and the challenges they faced. It also gives an overview of IoT, WSN, and shows their potential to revolutionize water management practices as well as their challenges and limitations.

- **Chapter three**(3) illustrates some relevant studies about the taxonomy of MAC protocols in WSN, with a brief show of their advantages and drawbacks and a concise comparison among them.

- **Chapter four**(4) presents the proposed MAC protocol, detailing its architecture and medium access mechanisms, focusing on the performance evaluation of the protocol through extensive simulations. It also analyzes and discusses the results.

- Finally, **Chapter five**(5) wraps up the dissertation by summarizing the key findings and offering recommendations for future research.

Chapter 2

Background

2.1 Introduction

Chapter 2 provides an in-depth exploration of water management systems, focusing on their operation and the challenges faced by water companies. It focus on the complexities of managing water resources, including the need for real-time monitoring and data collection to ensure efficient and sustainable water distribution.

The chapter emphasizes the importance of adopting innovative solutions to address these challenges, leading to the consideration of Wireless Sensor Networks (WSNs) as a remote monitoring and management solution. WSNs offer a promising approach to water management, enabling continuous monitoring of water quality, quantity, and distribution, thus enhancing overall system efficiency.

Furthermore, the chapter sets the stage for the detailed examination of WSNs in later chapters, focus on their potential to revolutionize water management practices. By leveraging the capabilities of WSNs, water companies can overcome existing challenges and improve the reliability and sustainability of their water distribution systems.

2.2 The water management mechanism within the Algerian water corporation (ADE)

2.2.1 Production

Water production from boreholes involves the use of submersible pumps within the well to extract ground water. Its capacity determines how fast it can pump and is measured in Gallons Per Minute (GPM), or m$\hat{3}$/h, that should be sufficient enough not to empty the well or result in excessive pressure cycles.

In this section, we will explain how production operations happen in a water management system and how they interact for a continuous supply of water. The figure 2.1 below provides a pictorial representation of an average operation. Throughout this process, monitoring, treatment, and infrastructure maintenance are important to guarantee the safety and reliability of the water supply.

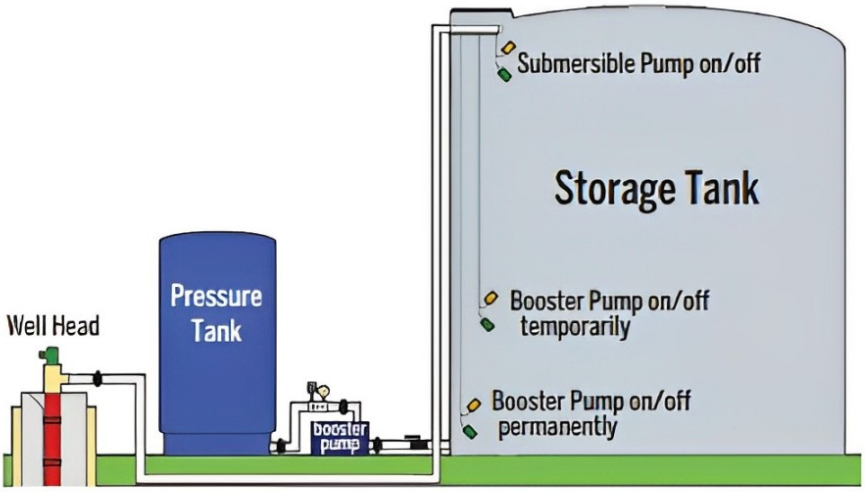

Figure 2.1: Water Production [1].

2.2.1.1 Quantity

The quantity of water drawn from the deep aquifer by the pump depends on factors such as aquifer depth, size, state, pumping rate, and the distance between the well and the reservoir. This pumping leads to an increase in the water level. Calculating the elution time of certain traces can be challenging, but it can be done using input specifications, relevant formulas, and research results on tracers. However, water flow can vary significantly between seasons, affecting its usability for different purposes. Therefore, preparation in advance is important.

2.2.1.2 Quality

For the quality of water, there are several steps, the most important of which are :

- **Initial Treatment** : The water quality and its utilization are two determinants of the treatment ; those steps could encompass shaking or filtering to remove debris and harmful contents.
- **Filtration** : Particularly, sand filtration systems or cartridge filtration systems could be used, not only to keep bigger floating solids out but also to improve water clarity by taking out the small suspended particles.
- **Disinfection** :One of the methods to get rid of those bacteria and micro is disinfection, whereby the waters intended for consumption must be subjected to chlorination for drinking or irrigation.
- **Desalination** : In areas with high salt content, such technologies are called desalting, which will allow making water salt-free, which will be necessary for various purposes for the crop.
- **Testing and Monitoring** : It must conform with the standards that are set for some specific use (e.g., for drinking or irrigation). This encompasses observing such things as chlorine levels and pH as well as contaminant presence.

2.2.2 Distribution

Water is distributed across the whole state through a network of underground transportation lines that runs long ways in order to be sure of continual supply to all areas. facilitating the efficient flow of enormous volumes of water from the huge reservoirs to districts that are urban and suburban at the center. While water is flowing through these canals, the size of the canals continually changes to fit the long way. The channels are made of strong conduits in the beginning in order that they can process large flows of water before gradually narrowing as they get to the point of usage to ensure proper water distribution and accessibility.

Another pious act carried out by these channels is that they determine the quantity and quality of water being delivered to end users.

The graphic below (figure 2.2) shows the initial idea of how water canals could connect in the city and be the basic distribution mechanism.

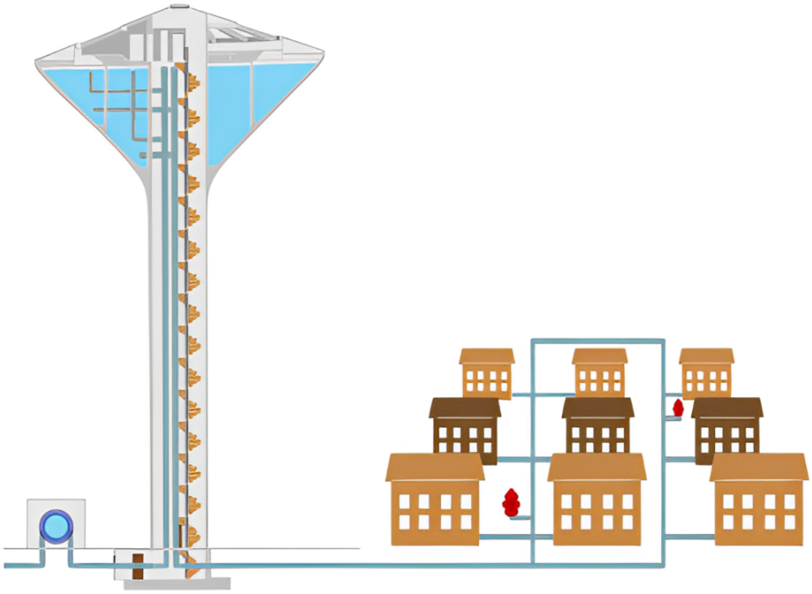

Figure 2.2: Water Distribution [2].

2.2.2.1 Quantity

This distribution method is operated by the very component that makes the water get through, which is the water pressure. Strictness of standards of pressure levels solves the problem of the difference in water pressure never exceeding more than 3 bars by the time the water gets to the tap to get a continuous smooth flow of water that caters to domestic needs, hence indicating the role of pressure in the distribution process as well.

2.2.2.2 Quality

Besides water quality precautions at the processing point, consumers at the terminal demand point cannot be overlooked either. The water will undergo a process to check the quality and chlorine of the water supply. The standard is to achieve a lowering of chlorine levels from a marked range of 0.2–0.4 mg/L for human use. Accordingly, the water is made as drinkable as possible, and the people's safety is fully or entirely ensured.

2.2.3 Poblems and challenges

The next table (Table 2.1) depicts the major problems that can damage Algerian Water Corporation ADE at the water acquisition and distribution, including water quantity, water quality, and water infrastructure.

	Quantity	**Quality**
Production	Insufficient supply and aging infrastructure Contamination and treatment Funding and management Dependence on unreliable sources Regional water shortages	Source Contamination Treatment Inadequacy Monitoring Insufficiency Leakage and Seepage Natural Contaminants
Distribution	Leakage at the level of water channels Low water pressure and flow	High concentration of chlorine in the water

Tableau 2.1: Production and Distribution Issues

The traditional system with the human aspect that could be prone to multiple difficulties that will hinder the process of fixing the problem and subsequently delivering water to the user, according to the corporation, is the central problem faced by them. Figure 2.3 defines these concerns :

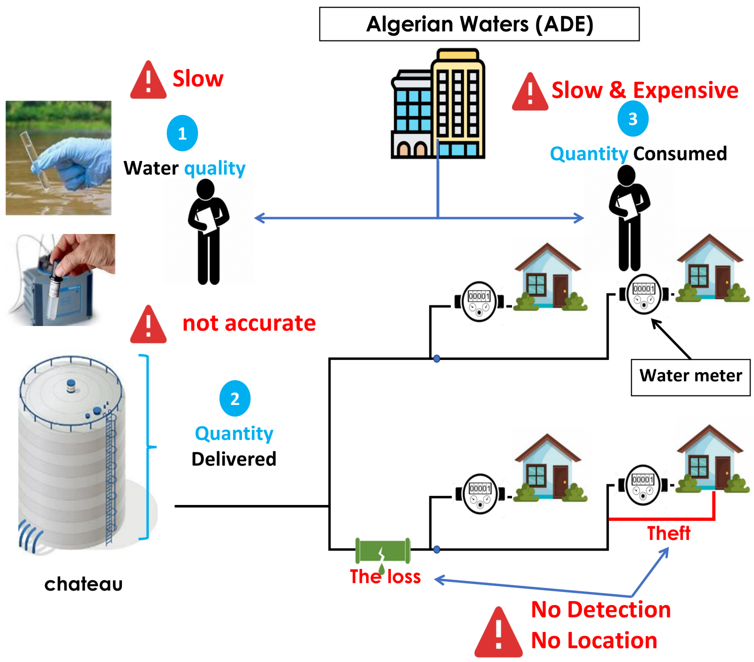

Figure 2.3: The problems ADE faces.

- **Expensive and slow :** This situation is related to both quality and quantity. It is expensive and takes time to supply a large amount of water while keeping it of the desired quality.

- **Inaccurate :** Sometimes it happens that in the water tanks, the amount of water given is either less or more than what is required.
- **Loss :** In channels, which is a common problem that occurs during drilling operations on a day-to-day basis and leads to corroding metals over time.
- **Theft :** which in turn implies that somebody adds their channels to the network and prevents subscribers from receiving water. Both theft and loss cannot be easily detected or located.
- Furthermore, when no mapping issues are concerned, natural causes can trigger them, and they could cause a great disaster.

2.2.4 Remote management as a solution

In the dynamic context of remote network monitoring, where networks span geographical borders and devices connect from several places, full visibility and real-time insights have never been more important. This is when network monitoring enters the picture [8].

Remote management is the administration, control, and supervision of computer systems and networks from a remote location, with several purposes, [9] including :

- Troubleshoot issues.
- Run updates on the operating system.
- Backup data.
- Monitoring the performance of a system.
- Overcome technical problems is wanted to do

Remote management may handle a variety of devices, including :

- Computers
- Servers
- Network devices
- Mobile devices

- Industrial equipment
- Sensors

WSNs can be an especially important instrument for the control of various aspects of water production, distribution, and quality. The reasons why WSNs can stand out among remote control systems in water companies are :

- **Remote Monitoring** : WSNs can be employed for quick, hassle-free monitoring of various water distribution parameters such as water quality, flow rate of water, pressure level, and others in real-time, whether human beings are involved or not.
- **Cost-Effective** : Nevertheless, in comparison to the traditional wired type of monitoring systems, WSNs consumes much less in relation to the infrastructure setup and the system maintenance within a multi-dimensional and distant water supply network.
- **Scalability** : Scalability is a fundamental feature of WSNs, and it presents the water companies with a good opportunity to spread their monitoring effort, whether by expanding their monitoring network as they grow or by having new monitoring goals.
- **Fault Detection and Maintenance** :WSNs can mark many positive outcomes through the detection of faults and leaks on the distribution system, and so, proactive maintenance and lower downtime days are ensured.
- **Data Collection and Analysis** : WSNs, especially when built with sensors dense across the network, may get involved in a long list of data acquisition that can be subsequently treated and further utilized to build up professional activities and decision-making.

Finally, WSNs give water suppliers a facility to just remotely control their distribution of water locally, as shown in Figure 2.4, which leads to better dependability, efficiency, and cost reduction in the management of water.

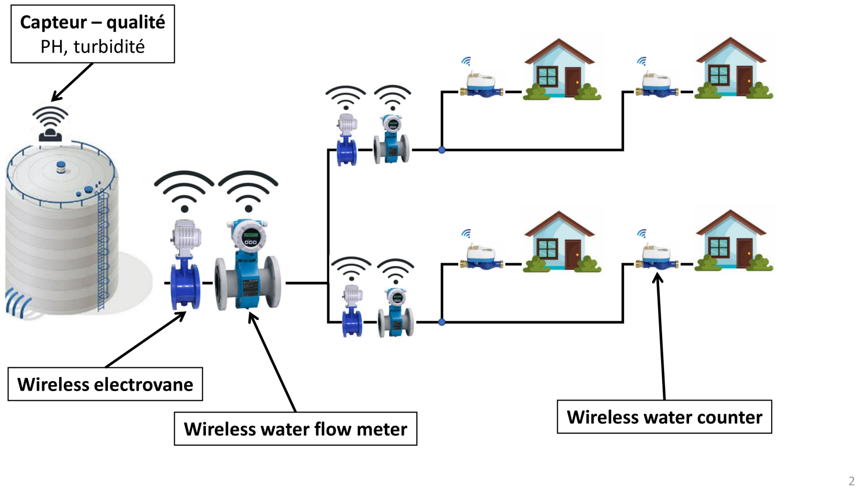

Figure 2.4: the proposed solution.

2.3 Wireless Sensor Network WSN

2.3.1 Difference between WSN and IoT

The term Internet of Things, known as IoT, is gaining more and more interest in society. It is a compromising concept that includes not only the sensors but all kinds of devices. These attributes allow the devices to connect with each other and share data via the Internet. More importantly, each device is being given an IP address (ID) [10].

Such stuff is hardware with great diversity. For example, it may be anything from low-cost consumer electronics (cars, home appliances) to large-scale industry infrastructure (Figure 2.5). Remarkably, the growth of this stress is predicted to make the data amount exceed the sum of all cellular infrastructure [3].

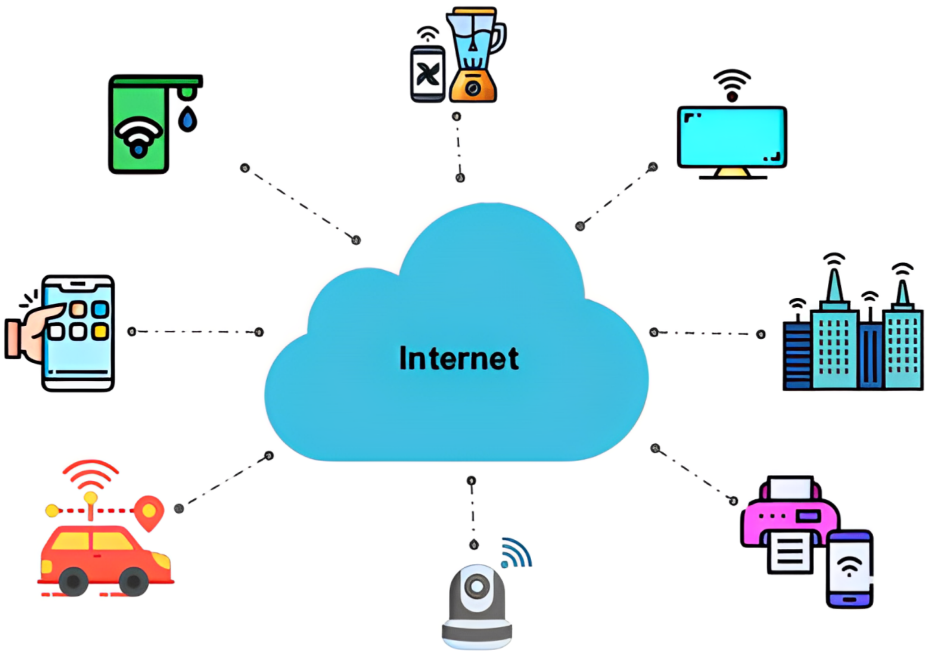

Figure 2.5: Internet of Things [3].

WSN stands for Wireless Sensor Network. It is like multiple battery-powered wireless sensing devices (sensor agents) that you can combine in various ways to measure different or more environmental and physical parameters in the specifically chosen area or the area accidentally covered with the sensors. Each sensor node collects local physical information, processes it, and transmits it wirelessly to a central node called base station (BS) or sink node, thus becoming the data gathering element. Sensor nodes send information about their neighborhood until the gateway, where the gathered data will be gathered [11].

For public notice of the phenomenon, the central node is connected to the internet. The data collected by the sensor nodes can be used for various applications, such as environmental monitoring, healthcare, and industrial. The design of the WSN is described. Figure 2.6 provides an explanation of the WSN's design [3].

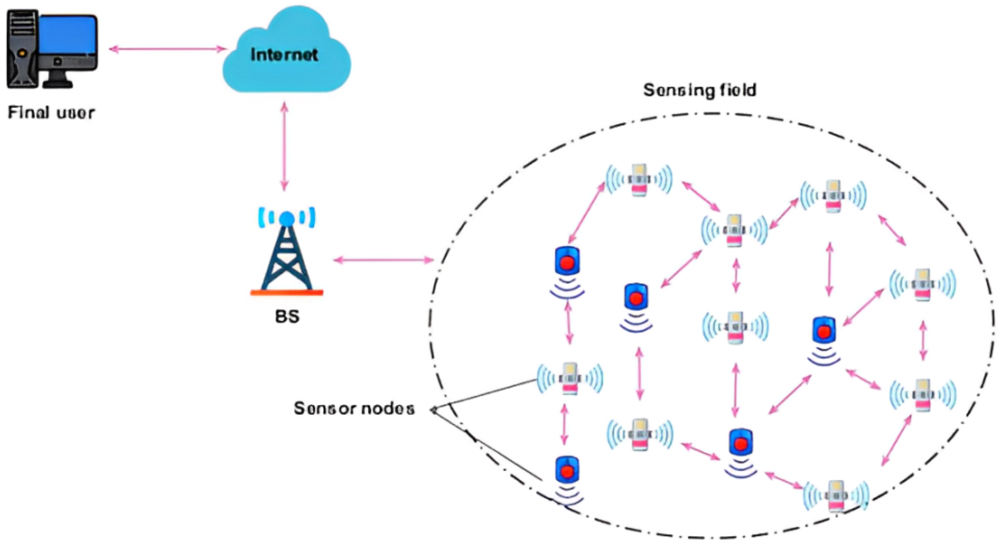

Figure 2.6: Wireless sensor network [3].

A WSN is among the rapidly expanding and booming parts of the already developing IoT arena. It is a key player in the creation of the Internet of Things (IoT), and in this process, it transmits data via numerous sensors. In this case, the data is set for analysis and decision-making.

The sensor nodes in IoT based WSNs strenuously study the residence around them and regularly inform the BS through wireless links whenever there is an event [3, 12].

2.3.2 Characteristics

WSN is gradually becoming one of the key monitoring systems by measuring different parameters without any supervision in the real-physical environment. Hence, for the network to be deployed efficiently, the characteristics of WSN must be considered. The following is a description of WSN's noteworthy features [13, 14] :

- **Low cost :** The WSN's main function is to ensure that a large number of sensing nodes are placed in the environment such that the nodes' cost at the end is minimum, and as a result, the cost of the network overall is reduced.
- **Energy-efficient :** The energy-consuming function of WSN lies in processing, transmitting, and storing, which are located in sensor nodes, which are the largest ones to use up power.
- **Communication Capabilities :** WSNs transmit wireless communication in a uni-

and bi-directional manner. Such communication requires radio waves as a transmission medium.

- **Security and privacy :** Highway-level security must be in place on sensors so that unintentional damage to data stored and end modifications to them will need strong security to avoid.
- **Distributed sensing and processing :** The uniformly distributed or randomly distributed density of sensor nodes in the WSN leads to distributed sensing and computing; meanwhile, system stability is ensured, as is data gathering, sorting, and processing.
- **Dynamic topology of the network :** This is because the WSNs are the networks that are of a dynamic nature, and so the nodes should be attached to a mechanism that should be able to self-adapt and reconfigure on the communication channels or a fault with the sensing.
- **Self-organization :** As sensor nodes in a network are usually placed in the unfrequented and no one has visited them or they have never been monitored so far, they ought to perform in a coordinated and self-organized manner, thereby co-designing and adapting their own distributed algorithms autonomously.
- **Multi-hop communication :** Nodes that will enable multi-hop communication are required because of the transformation of an effective path through which a node relays data to another distance point that may be beyond the radio frequency limit.
- **Application-oriented :** WSNs are customized according to the given application, where the nodes are subject to random distribution to meet the particular needs of each application.
- **Robust Operations :** Sensor nodes have to be error- and fault-tolerant, which provides for self-testing, self-calibration, and self-repairing capabilities, to achieve long-lasting functioning in large, aggressive environmental conditions.
- **compact physical size :** Their area of performance is necessarily limited, therefore they are tiny and weightless, which leaves them with little energy and power for communication [14].

2.3.3 Sensor unit architecture

Sensor, which is a device, has the capability of receiving and sending data from the real world to other systems and devices for processing (Figure 2.7) [3].

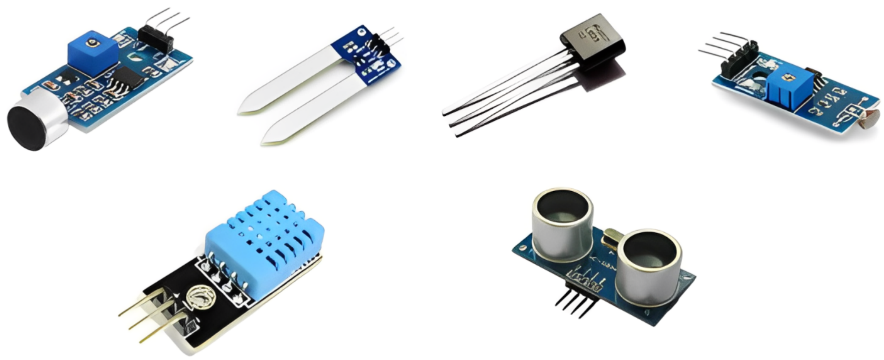

Figure 2.7: Sensors [3].

As seen in Figure 2.8, the architecture of a sensor typically consists of four basic parts : a transceiver unit, a processing unit, a power unit, and a sensing unit [3, 15].

- The sensing unit consists of two sub-units : there is a block with the name ADC, or analog/digital converter, and it changes the signal from analog to digital. The physical catching device, or the physical detector, is responsible for scanning for physical changes in the environment.
- The data acquired by the sensing system, which is the comprising element of the memory, is processed by the signal analyzer.
- The transceiver located at the communication interface is responsible for the communication between all network nodes. The transmitter/receiver (radio module) is the actual communication interface.
- Often, the power part is a rigid battery. The energy utilization at a very low level of sensors is the biggest issue that we face during the design of networks [3].

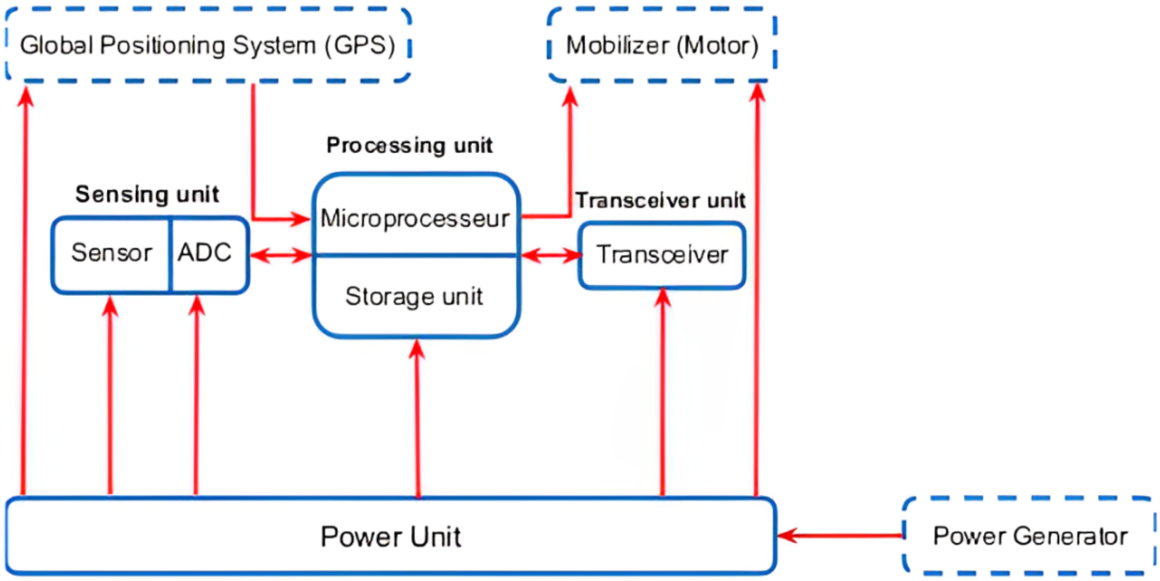

Figure 2.8: actuator unit [3].

On the other hand, sensor nodes are wireless and cheap, but need add-on feature like motor and Global Positioning System (GPS) for the purpose of motion and location data. They depict the combination of software and hardware that contain communication protocols, low power operating systems and application software [3].

2.3.4 Network categorization

There are numerous ways to classify WSNs, each of which focus on their distinct qualities and provides adaptable solutions for a range of applications [16] :

2.3.4.1 Categorized by Applications

- **Health monitoring :** WSNs offer several healthcare applications, including medical wearables and aids for hospitals and homes, relying on the latest medical sensors for real-time patient parameter monitoring.

- **Urban :** In light of the WSNs providing rich data for smart homes, transit systems, and structural health monitoring in urban areas, which are by nature location- and time-dependent, the networks feature precision and diversity instrumentation-wise.

- **Environmental :** Distinguished from the ubiquitous technologies working with smart sensors, these specialized sensors can be implemented in water, air, and emergency alerting systems to allow for continuous monitoring of difficult and inaccessible places.

- **Military :** By using different sensor types, the military is the leader in the integration of WSNs for surveillance of fights and intruder detection, troop monitoring, and battlefield surveillance.

- **Industrial :** iwsns are multipurpose in nature, being cheap and effortless to deploy and also mobile, and with clever network routing, they appear to be the best choice as a communication option for industrial applications [16].

2.3.4.2 Categorized by Different Network Topology

- **Star :** A star topology ensures the effortless deployment since all sensors are able to communicate with the center hub or gateway without difficulties.

- **Mesh :** A mesh network which is self-healed and has redundancy, requires internal communication among sensors through its vicinal nodes.

- **Tree :**there are tree-like data flows from leaf nodes to a central sink node which is able to perform well aggregations of data.

- **Hybrid :** introduce various topologies to ensure that the coverage, efficiency, and reliability are achieved [16].

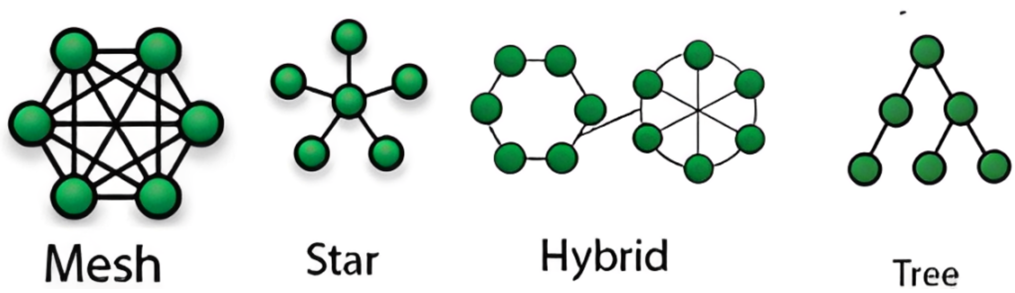

Figure 2.9: Different Network Topology.

2.3.4.3 Categorized by Physical Environment

- **Underground :** WSNs lying beneath the surface areas of the Earth, whereby are often designed for geological monitoring and mining.

- **Terrestrial :** Such networks are being based on land and are being used for different types of transportation, smart farming, and environmental sensing.

- **Underwater :** Submerged WSNs that are immersed in marine habitats are of great importance for observing the situation of aquatic environments, oceanographic research, exploration activities on the sea floor, and marine research.

- **Multimedia :** such networks are useful in apps like video streaming and image downloading data collection on scales, time, and space dimensions because they process multimedia material.

- **Mobile WSNs :** The most appealing thing is that mobile WSNs are quite easy-to-use and customizable, which means they are ideal for monitoring situations that can change very fast and need quick reactions applications, for example, eHealth platforms, vehicle networks, and animal tracking [16].

2.3.5 Protocol stack (Layer architecture)

WSN is a scattered system of devices for smart cities, healthcare services, industrial automation, and environment monitoring. Yet, they have a cap on their computational process, memory, and energy, which, in turn, may be counterproductive.

In this way, it is one of the most important points to control the quality of WSN communication protocols and standards in order to maintain network productivity, reliability, and performance.

The WSN protocol stack based on the International Organization for Standardization's (ISO) layer-7 model has been developed as the fundamental structure of the protocol. Indeed, the WSN protocol stack is quite different from the OSI model, where unlike the OSI model, the stack does not encompass all seven layers. Because the OSI layers are complex, it is not easy to implement. The five-layered protocol stack used in WSNs makes the visual representation easier in Figure 2.10 [3, 17].

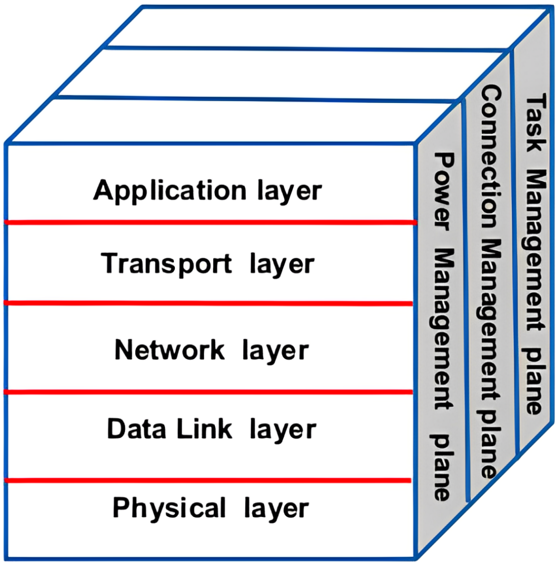

Figure 2.10: Protocol stack for WSNs [3].

In contrast, the protocol stack itself is grouped into discretionary planes that consist of task management, connection management, and power management constituent systems of each layer [3, 17].

- **Physical Layer :** The Physical Layer is located at the lowest OSI model and brings the transmission and receipt of raw bits that are responsible for signal frequency, modulation, and coding, including power.

- **Data Link Layer :** The Data Link Layer being one of the indispensable parts of the OSI model is the one that subsidizes the packet transfer between different network nodes by controlling packet latency, throughput, and fairness.

- **Network Layer :** The Network Layer is the third layer of the OSI stack, where the protocols for routing as well as addressing schemes are defined and end-to-end data delivery is guaranteed between the nodes.

- **Transport Layer :** The Transport Layer is the OSI model's fourth layer, which is considered the one making sure the reliable and efficient delivery of data, an exchange of data between applications in a network.

- **Application Layer :** The Application Layer is the highest OSI layer and is a crucially important part of the WSN communication process as it embraces the functionalities of different data exchange protocols and provides their own services [17].

2.3.6 Standards and protocols for MAC

The MAC protocols provide an essential role in a wireless communication network; they determine how devices access and use the limited resource shared medium.

2.3.6.1 MAC Protocol Categories

The availability of medium-access protocol rules makes networks that are shared accessible in an orderly manner. This allows all parties involved to share a limited wireless bandwidth. MAC protocols can be broadly categorized into three main categories based on their access mechanisms :

Contention based MAC (CSMA-based)

The contention-based approaches are based on carrier sensing (CS), back-offs, and re-transmission schemes :

- **Carrier Sensing (CS) :** The basic idea of CSMA/CA is “to listen before talk", meaning that the station starts by assessing the channel before transmission to determine whether it is busy or not. Clear Channel Assessment (CCA) is the name for channel monitoring, and it can be performed both through physical and virtual mechanisms. Physical carrier sensing consists of listening to the channel, and if it is free for a certain period of time, called an arbitration inter-frame space (AIFS), the sender can transmit directly so that direct collisions can be avoided.

- **Back-off :** In wireless networks, if the channel is busy during the AIFS, a node (or device) will wait for the channel to become free again and then perform a back-off procedure to defer its access. The back-off is a randomized period of time generated from a retention window (CW), which is a range of values that determines the length of the back-off period.

- **Re-transmission :** The MAC protocol of 802.15.4 is a stop-and-wait protocol. After sending a message, the sender will wait for an ACK. If it does not be received for some reason, the re-transmission of the message will be launched to give those who want to send it over a longer time period another chance. Before every re-transmission attempt, the size of CW will be doubled from its previous value, and a back-off procedure must be invoked. After a successful transmission or when the message had to be thrown away because of reaching the maximum value (CWmax), the CW will be set to its initial value again (CWmin).

  In the broadcast scenario, the message is sent to every node inside the transmission range, not to a specific receiver, and if the receivers return their ACKs, multiple collisions will happen. Thus, this kind of communication does not use most of the CSMA/CA mechanisms that rely on the receiver's feedback. Therefore, no ACK will be sent by the receiver, and the sender will never know if the surrounding nodes have received the transmission message correctly or not. Moreover, the broadcast messages will never experience multiple re-transmissions and back-offs ; the contention window will always be in its initial value (CWmin), and the sender will perform just one back-off when it senses a busy channel. As a result, the prevention of hidden collisions is not as effective as in the uni-cast transmission, as shown in Figure 2.11.

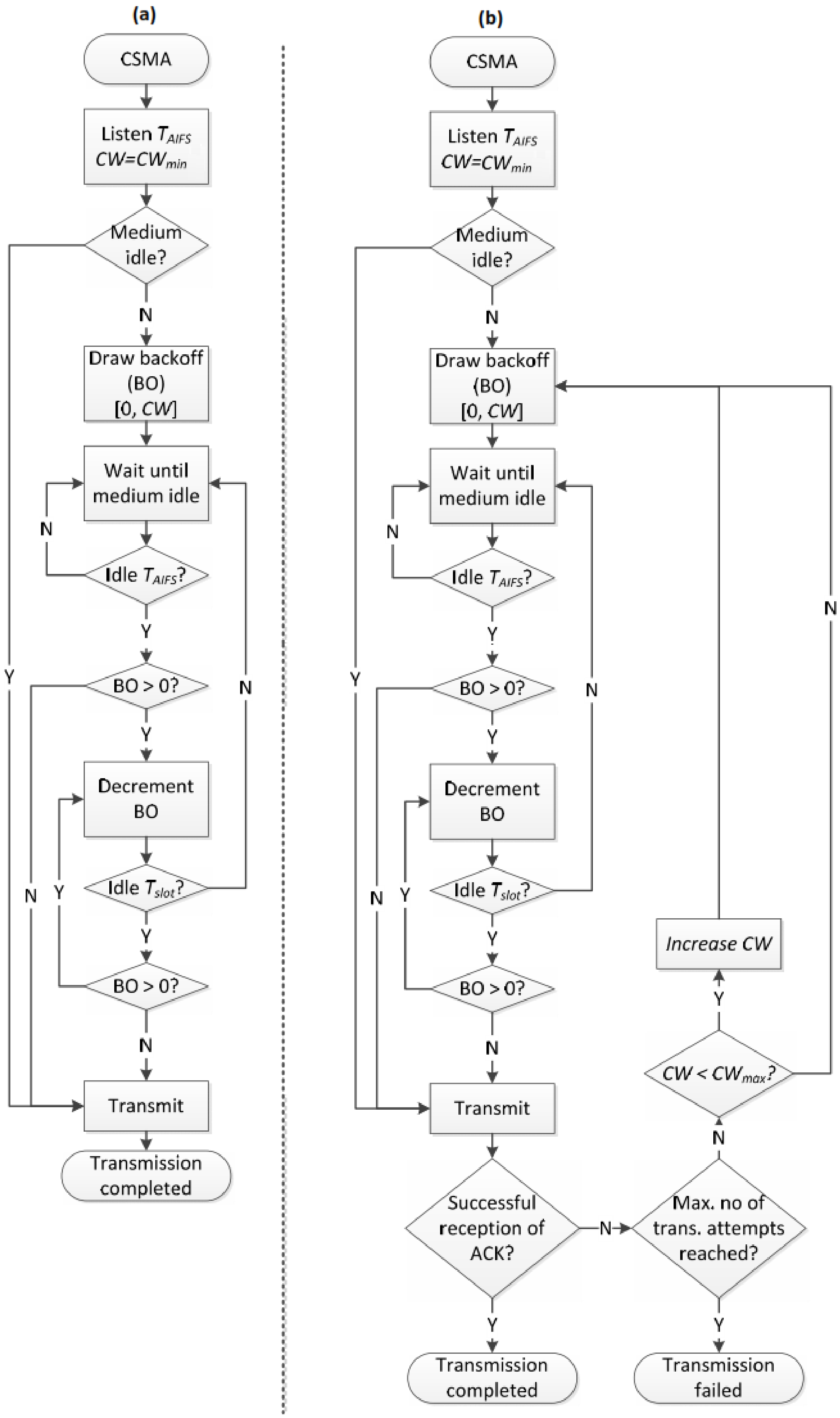

Figure 2.11: CSMA channel access procedure ; (a) broadcast mode, and (b) uni-cast mode.

Scheduled based MAC (TDMA-based)

Scheduled-based MAC (TDMA-based) is a type of Medium Access Control protocol that divides time into fixed slots, with each slot assigned to a specific node for transmission. This deterministic scheduling helps eliminate sources of energy waste, collisions, and idle listening, which can occur in random access methods.

With scheduled-based MAC, only one pair of transmitter-receiver remains active at every transmission period, reducing collisions and eliminating idle listening and overhearing. This approach is particularly useful in sensor networks where radios can be switched off during idle times to conserve energy. However, maintaining accurate synchronization between sensors can introduce a large overhead. Additionally, latency increases with the total number of sensors sharing the same channel, as each sensor is assigned a separate time slot [5].

Hybrid MAC

Hybrid MAC is a combination of different protocols such as contention-based MAC and scheduled-based MAC to optimize the performance of WSN. For example, contention-based MAC protocols, such as CSMA/CA, allow nodes to access the medium based on a random backoff interval, which reduces collisions but may result in inefficient utilization of the channel. On the other hand, scheduled-based MAC protocols, such as TDMA, divide the channel into time slots and assign them to different nodes, which can achieve high utilization but may not be flexible enough to adapt to changing network conditions. Hybrid MAC solved the issue by using other MAC protocols, During the transmission of data, if the channel is idle or has low traffic, then hybrid MAC switches to contention-based MAC. If the traffic in the channel increases, then it is switched to a scheduled-based MAC such as TDMA [18].

2.3.6.2 Introduction to Key MAC Protocols : S-ALOHA and CSMA

Understanding key MAC protocols like Slotted ALOHA (S-ALOHA) and Carrier Sense Multiple Access (CSMA) provides insight into how different mechanisms handle data transmission, reduce collisions, and improve network efficiency.

Slotted ALOHA (S-ALOHA)

Aloha is a basic communication protocol where each network source transmits data whenever it has a frame ready. Successful transmissions prompt immediate next-frame transmissions, while failures due to collisions lead to retransmission attempts of the same frame. It functions well in wireless broadcast or half-duplex links. However, in complex networks like Ethernet, where multiple sources share a common data path, collision issues escalate with higher communication volumes. Slotted Aloha improves upon this by introducing fixed time slots for transmissions, aiming to boost throughput and reduce collisions compared to Aloha [19].

Carrier Sense Multiple Access (CSMA)

CSMA is a probabilistic MAC protocol where a node checks if the channel is clear before transmitting on a shared medium like an electrical bus. It listens for signals from other stations ; if the channel is sensed busy, it waits until the ongoing transmission ends. The term "Multiple Access" signifies that multiple stations can send and receive signals on the channel, where transmissions by one node are typically heard by all others. CSMA/CD (Collision Detection) improves CSMA by halting transmission upon detecting a collision, while CSMA/CA (Collision Avoidance) enhances it by delaying transmission for a random interval if the channel is found busy before attempting to transmit.

Difference between CSMA and ALOHA

Table 2.2 presents a comparative analysis between S-ALOHA and CSMA protocols. This comparison show key differences in their operational principles, efficiency, collision handling mechanisms, channel utilization, and suitability for different network environments.

Tableau 2.2: Comparison between S-ALOHA and CSMA

Feature	**S-ALOHA**	**CSMA**
Basic Principle	Simple transmission without checking channel status before sending	Verifies channel status (Carrier Sense) before transmission
Transmission Strategy	Sends data frames immediately	Waits if channel is sensed busy before transmitting
Efficiency	Lower efficiency due to potential collisions	Higher efficiency by avoiding collisions through sensing
Collision Handling	Collisions may occur and need re-transmission	Collisions detected early (CSMA/CD) or avoided (CSMA/CA) with back-off
Channel Utilization	Less efficient use of channel bandwidth	Efficient use with minimized idle time and collisions
Application	Suitable for low-traffic or sporadic data transmission	Suitable for networks with moderate to high traffic volumes
Protocol Standards	Simple, less overhead	More complex, with additional collision detection and avoidance mechanisms

2.3.6.3 IEEE 802.15-Wireless Specialty Networks

- **Description**

  IEEE 802.15. is the working group for WSNs, or wireless specialty networks, such as wireless personal area networks (WPANs), Bluetooth, Internet of Things networks, mesh networks, body area networks, wearables, visible light communications, etc. The 802.15 working group says it "focuses on the development of open consensus standards addressing wireless networking for the emerging (IoT), allowing these devices to communicate and interoperate with one another, mobile devices, wearables OWC, autonomous vehicles, etc. The goal is to publish standards, recommended practices, or guides that have broad market applicability and deal effectively with the issues of coexistence and interoperability with other wired and wireless networking solutions. The working group has completed a large body of work. Many of its standards, particularly IEEE 802.15. Std. 802.15.4, are widely deployed around the world. The Working Group strives to be an incubator for new technologies and applications and has published the first standard utilizing the Terahertz (THz) radio frequency frequency bands for high-speed wireless interconnection and reconfiguration of data centers. 802.15 is also the first organization to produce global standards for OWC. The IEEE 802.15. 802.15 Working Group is part of the 802 Local and Metropolitan Area Network Standards Committee of the IEEE 802.15. Computer Society [20].

- **Standards**

  The IEEE 802.15. Working Group defines a series of standards for (WPANs) and other short-range wireless communication technologies. Here's a breakdown of some key standards within this group :

  - **IEEE 802.15.1** : This standard specifies the foundation for WPANs, including both (MAC) protocol and Physical Layer (PHY) specifications. It defines how devices access the shared wireless channel and the physical characteristics of the signal transmission.
  - **IEEE 802.15.2** : Coexistence of Wireless Personal Area Networks with Other Wireless Devices Operating in Unlicensed Frequency Bands
  - **IEEE 802.15.3** : This standard caters to high-data-rate wireless networks suitable for multimedia applications within a WPAN. It provides specifications for higher bandwidth compared to other standards in the group.

– **IEEE 802.15.4** : This widely used standard addresses low-rate wireless networks. It's particularly well-suited for resource-constrained devices in sensor networks and other applications where low power consumption and data transmission are crucial.

– **IEEE 802.15.5** : This standard extends the capabilities of WPANs by enabling mesh networking. Mesh networks allow for multi-hop communication, where data can be relayed through multiple nodes to reach its destination, extending the network's reach.

– **IEEE 802.15.6** : (WBAN) standards are outlined in this standard. The purpose of these networks is to facilitate communication between wearable technology on or near the human body.

– **IEEE 802.15.7** : This standard emphasizes the use of visible light for short-range optical wireless communication, offering an alternative to radio frequency (RF) communication in certain situations.

– **IEEE 802.15.8** : This standard defines mechanisms for peer-to-peer communication between devices without the need for a central coordinator.

– **IEEE 802.15.9** : This standard specifies a key management protocol to ensure secure communication within WPANs. It provides mechanisms for authentication and encryption of data [21].

– **IEEE 802.15.10** : Layer 2 Routing, Practice for Routing Packets in IEEE 802.15.4 Dynamically Changing Wireless Networks [20].

These standards cover a wide range of wireless communication technologies and applications, each addressing specific needs and requirements in the wireless networking domain.

2.3.6.4 IEEE 802.15.4 for PHY and MAC Layer Communication

IEEE 802.15.4 is a radio technology standard that defines both PHY and MAC layers for low-power and low-data-rate communications. Due to its low power consumption, low cost, and flexibility, it has been used in many industrial applications but also in other fields, such as health monitoring and smart home energy management systems.

The original IEEE 802.15.4 standard from 2006 was amended throughout the years to a IEEE 802.15.4.e version that is of particular interest for our discussion as it supports time-synchronized channel hopping communication. We discuss three versions of the IEEE 802.15.4 standard, which are :

- **IEEE 802.15.4 PHY** : The standard supports 11 channels in the low-frequency band (868/915 MHz) and 16 channels in the high-frequency ISM radio band (2.4 GHz). In order to achieve less interference along the frequency bands and an improved signal-to-noise ratio, the standard employs different modulation techniques.

- **IEEE 802.15.4 MAC** : The standard manages access to physical channels and time slots, frame detection, and node association, and it uses the CSMA/CA method. It has two channel access modes, and it defines different types of devices, which provides the possibility of having different network topologies (star, peer-to-peer, cluster).

- **IEEE 802.15.4.e MAC** : The revised version of IEEE 802.15.4 MAC supports multi-hop communications by employing Time Synchronized Mesh Protocol (TSMP). Devices are synchronized to a schedule that indicates to which neighbor to communicate and on which channel.

Figure 2.12 depicts the IEEE 802.15.4 frame structure. The PHY frame contains a synchronization header, which consists of a preamble, the Start of Frame Delimiter (SFD) to indicate the start of an arriving packet, and the PHY Header (PHR) to indicate the length of the payload. These are followed by a fixed-size payload of 127 bytes. The MAC frame includes the header (control field, sequence number, and address), payload of the variable size, and Frame Check Sequence (FCS) used to verify the integrity of the frame. The whole MAC frame size has to be less than 127 bytes to satisfy the size constraint of the physical layer [4].

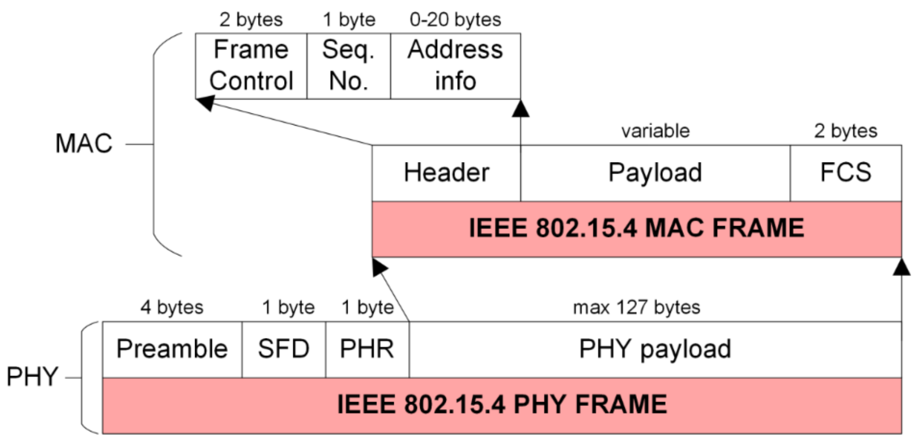

Figure 2.12: Typicall IEEE 802.15.4 frame on a 2.4 GHz network [4].

2.3.7 Technologies

The following section introduces several key wireless communication technologies commonly used in various applications :

- **ZigBee :** ZigBee serves as a wireless network data transmission protocol, supporting mesh and cluster tree architectures. Its functionality, akin to Wi-Fi, distinguishes itself through lower energy consumption, modest bit rates (up to 200 and 50 kbps), and an operational range of about 100 m. ZigBee enables two-way communication, allowing devices to both send and receive signals, with some capable of relaying signals. Developed by the ZigBee Alliance in 2002, this technology boasts collaboration from numerous globally recognized companies, including Samsung, Philips, Siemens, Bosch, Motorola, Amazon, and Xiaomi. The initial ZigBee specification, Version 1.0, emerged in 2004, followed by the introduction of ZigBee 3.0 in 2016 [16].

- **Bluetooth :** Bluetooth technology owes much of its success to the remarkable flexibility it affords developers. With two radio options, Bluetooth caters to a diverse range of wireless connectivity needs, making it a preferred choice for various applications. Whether facilitating high-quality audio streaming, data transfer between devices, or communication in building automation, Bluetooth Low Energy (LE) and Bluetooth Classic radios offer tailored solutions to developers worldwide. The Bluetooth LE radio, designed for ultra-low-power operation, operates across 40 channels in the 2.4 GHz unlicensed ISM frequency band. This design grants developers significant flexibility in crafting products that align with the specific connectivity demands of their target markets. Bluetooth LE supports various communication topologies, extending from point-to-point to broadcast and, more recently, mesh, enabling the creation of dependable large-scale device networks. Initially renowned for device communication, Bluetooth LE has evolved into a prominent device positioning technology, meeting the rising demand for highly accurate indoor location services [16].

- **WirelessHART :** WirelessHART is a radio communications protocol that enhances the widely used HART protocol with wireless capabilities while maintaining compatibility with existing devices, commands, and tools. It operates in the 2.4 GHz ISM band using IEEE 802.15.4 standard radios and features a time-synchronized, self-organizing, and self-healing mesh architecture. In a WirelessHART network, each device acts as both a signal source and a repeater, enabling signals to be routed across the entire network, expanding its reach throughout the facility or field application. The network consists of wireless field devices connecting to plant equipment, gateways facilitating communication with hosted applications, and a network manager responsible for configuring the network and managing communication and message routing, typically integrated into the gateway [22].

- **LoRaWAN :** LoRaWAN a prominent LPWAN technology—has garnered substantial attention from the research community. Developed by Semtech Corporation, it facilitates long-range data transmission with low data rates. Using a chirp spread spectrum (CSS) modulation where the chirp signal frequency varies, LoRaWAN ensures robust coverage. The modulation employs spreading factors (SFs) ranging from 7 to 12, with higher SFs providing better coverage but at the expense of data rate and power efficiency [16].

- **NRF24L01 :** The nRF24L01 is a single-chip 2.4 GHz transceiver with an integrated baseband protocol engine (Enhanced ShockBurst^{TM}), designed for ultra-low-power wireless applications. It works in the ISM frequency band of 2.400–2.4835 GHz worldwide. A radio system with the nRF24L01 requires only a microcontroller (MCU) and very few external passive components. It can be configured and operated over a serial peripheral interface (SPI), thus giving the programmer access to the register map of this device. Various packet-based communication modes are supported by the included baseband protocol engine, from manual operation to autonomous protocol operation.Integrated FIFOs provide smooth data flow between front-end radio and MCU. Gaussian Frequency Shift Keying (GFSK) modulation is used for communication.The supported air data rate is configurable up to 2 Mbps, making it low-power-friendly. The nRF24L01 operates in a frequency range of 2.4 GHz to 2.525 GHz in the ISM band, with 125 channels available to avoid interference with neighboring modules.

2.3.8 Communication requirements

Effective communication in any network, whether wired or wireless, is influenced by several requirements and challenges. These factors are shaped by various aspects, such as the environment and the nature of the communication itself. In wireless networks, these requirements can be summarized as follows :

2.3.8.1 Performance requirement

The performance requirements of a MAC protocol are important to ensuring efficient and reliable communication in a WSN. Here are some of the key performance requirements of a MAC protocol :

- **Energy Efficiency** : WSNs typically operate on battery power, so a MAC protocol should minimize the energy consumption of wireless sensor nodes by reducing the time that nodes spend in the active state and maximizing the time spent in the sleep state. This can be achieved through mechanisms such as duty cycling, where nodes alternate between active and sleep states.

- **Latency** : Latency is the time delay between the transmission of a packet and its receipt at the destination node. A MAC protocol should minimize latency by reducing the time spent waiting for access to the wireless medium and by minimizing the time spent transmitting and receiving packets. This can be achieved through mechanisms such as contention resolution, where nodes compete for access to the wireless medium, and prioritization of packets based on their urgency.

- **Fairness** : Fairness is the equal distribution of network resources among all wireless sensor nodes. A MAC protocol should ensure fairness by giving each node an equal opportunity to access the wireless medium and by preventing any node from monopolizing network resources. This can be achieved through mechanisms such as randomized backoff, where nodes wait for a random amount of time before attempting to transmit.

- **Scalability** : Scalability is the ability of a MAC protocol to support large numbers of wireless sensor nodes. A MAC protocol should be designed to scale to large networks while maintaining its energy efficiency, throughput, latency, and fairness performance requirements. This can be achieved through mechanisms such as hierarchical clustering, where nodes are organized into clusters with a hierarchical structure [23].

2.3.9 Challenges

In spite of their highly practical usefulness, there are some challenges in wireless sensor network systems :

- **Mobility :** The high mobility of nodes and the rapidly changing network topology cause a short connection lifetime between nodes. Therefore, CSMA/CA protocols should support this feature by being decentralized and connectionless.

- **Nodes memory :** The wireless sensor nodes have limited memory and computational capabilities. In addition, the WSNs have been applied in harsh and inaccessible environments for a long time [24].

- **Hidden terminal problem :** A hidden node is defined as a node that is within the range of the destination node but out of range of the transmitting node [25].
- **Scalability and Congestion Problem** In a wireless network, the number of nodes cannot be known, is unpredictable, and is impossible to restrict. This situation causes high congestion on the channel and increases the problem of collisions.
- **Energy efficiency** As wireless sensor nodes have to work on a limited power supply, the design of the software and the hardware has to be optimized so that they can efficiently perform the designated job [26, 27].
- **Security** Like all internet-dependent applications, WSN also has insecurity scares. Proper data transmission management should be adopted to counter data theft in every possible way [27].

2.4 Conclusion

The second chapter introspectively explores water management in ADE. Then suggest WSN as a solution for the corporation's limitations. Another thing worth noting is the essence of WSN networks as well as the Internet of Things. studying their functions, characteristics, and structure.

Moreover, the chapter sorts the WSN based on application categories, network topologies, and physical settings ; In general, these divisions uncover numerous types of deployments. This part also gathers the protocol stack and standards of the "MAC" area of WSNs, and the different protocol categories are with the standards mentioned and described.

Besides ZigBee, Bluetooth, and other telecommunication system technologies such as LoRaWAN and NRF24L01, as well as others, there is a core overview of them discussed in the chapter.

As a result, Chapter 2 has set up a sturdy cornerstone for grasping water management in ADE as well as the fundamentals of WSNs. This understanding will, consequently, be the basis for later chapters of this study, which will focus on the usage of WSNs specifically for water management applications.

Chapter 3

Related work

3.1 Introduction

Wireless sensor networks (WSNs) have brought together the development of small, low-consumption, and versatile wireless sensor nodes due to manufacturing upgrades, electronics, communication, and miniaturization, which have highly contributed to the development of WSNs [28,29]. These sensor nodes are compartmentalized with embedded environment sensing, data acquisition, processing, and wireless transmission functionalities, whereby the WSNs are attributed with the ability to perform multiple tasks and recognize events across different usage sectors, such as the monitoring, tracking, surveillance, and reporting of specific events [30].

Moreover, as energy conservation has become one of the major matters to tackle along with the introduction of the Internet of Things (IoT), researchers have directed their attention towards the design of the WSN, which would minimize the energy consumption, i.e., memory size and protocol complexity. As the underlying things in the Internet of Things grow in number and they probably function as the sole purpose connectivity device, there is a need to adequately suit this trend by conducting more research [5,31].

In this chapter, we'll talk about the taxonomy of MAC protocols in WSN and classify them into three categories : contends, schedule-based protocols, and hybrid types. Moreover, we'll prepare review on every existing protocol, categorize which one is more or less feasible,and figure out their limitations.

The MAC layer plays a serious role in Wireless Sensor Networks (WSNs) by governing how nodes access the shared communication medium. Over the years, a diverse range of MAC protocols has been developed to address the unique challenges posed by WSNs, such as energy efficiency, scalability, and reliability. This chapter provides a comprehensive overview of MAC techniques for WSNs, focusing on their evolution, categorization, and performance characteristics. By examining the literature and classifying existing MAC protocols, this chapter aims to shed light on the strengths and limitations of current approaches, as well as identify areas for future research and innovation in the field.

3.2 Taxonomy

MAC protocols in WSNs can be broadly classified into two main categories : contention-based and scheduled-based.

3.2.1 Contention-based MAC

Contention-based protocols involve competition among nodes to access the shared wireless medium. Nodes send messages after a fixed time, only if the channel is not busy. These protocols are easy to implement and do not require direct commands or synchronization signals, making them adaptable to changes in traffic load, node count, and topology. However, they are energy-consuming due to collision avoidance mechanisms and control packets, especially in networks with small packet sizes.

There are two common types of contention-based MAC protocols for WSNs : synchronous and asynchronous.

Synchronous protocols use scheduling or synchronization to coordinate node activity, allowing nodes to know when to listen for packets and when to sleep, thus saving energy. However, excessive or infrequent synchronization messages can burden the network or reduce its adaptability to node mobility. Hence, handling the synchronization messages becomes an imperative for high performance of synchronous protocols in WSN.

Asynchronous protocols operate without synchronization among nodes, using techniques like Low Power Listening (LPL) [32] or preamble sampling [33, 34]. Receivers periodically wake up from sleep mode to check for data transmissions, conserving energy. They remain active only during actual data transmission. This approach reduces transmission overhead and long wait times and adapts well to network topology changes. However, long preambles can increase power consumption, cause excess emissions, increase delay at each hop, and lack distributed collision resolution.

Solutions to these challenges include :

1. Using shortened preamble lengths.

2. Receivers acknowledging transmitters to stop the preamble and start data transmission immediately.

3. Including receiver addresses in preambles.

These solutions aim to deliver energy-efficient and reliable communication in WSNs by minimizing energy consumption, reducing delay times, and ensuring reliable communication [5].

3.2.2 Scheduled-based MAC

The scheduled protocols in WSNs involve dividing network resources (time and frequency) according to a planned schedule to prevent collisions. This slot scheduling technique saves energy by allowing nodes to sleep during unused slots, reducing idle listening and overhearing.

Unfortunately, scheduled protocols add control overhead, increasing energy inefficiency due to the energy spent setting up and maintaining the schedule. However, the low mobility of sensor nodes leads to infrequent schedule changes, making the overhead trivial for long-term sensor node life.

Typically, distributed transmission scheduling is managed by a base station that assigns collision-free time slots to nodes. Scheduled protocols are ideal for networks with low node mobility and minimal topology changes. In such cases, centralized scheduling simplifies resource allocation and network performance management.

In TDMA-based protocols, a single frequency channel is divided into time slots, with each node assigned a dedicated slot, preventing collisions. However, tight clock synchronization is required, demanding frequent message exchanges. TDMA reduces channel contention but may cause delays and lower channel redundancy compared to CSMA, which allows free node transmission but can lead to collisions when nodes compete for communication opportunities [35].

FDMA protocols split the bandwidth into multiple frequency bands, assigning each node a unique frequency to avoid collisions. This approach requires high-powered technology capable of multi-frequency support, increasing costs.

OFDMA, a multi-user version of OFDM, divides radio signals into smaller symbols sent simultaneously on different frequencies, reducing transmission spillover. This method is used in fourth-generation wireless networks but involves complex OFDM architecture, sophisticated electronics, and higher power consumption due to the FFT algorithm. Despite its ability to hibernate for efficient resource management, the FFT continues operating unnecessarily, leading to inefficiencies. Additionally, managing co-channel interference in OFDM networks requires coordination among adjacent base stations and dynamic channel arrangements [5].

3.2.3 Hybrid MAC

In the case of the hybrid MAC protocols used in WSNs, in many cases one would go for FDMA, TDMA, and contention-based protocols together. These protocols divide time into two distinct periods : contention and scheduling periods.

contention period, which is usually applied for broadcasting purposes, is the period in which nodes attempt to seize channel access with a common broadcast frequency. In this phase, access to the channel is being granted by means of the contention scheme. Meanwhile, when the contention-free period is on, the connection of the devices are made-to-orders by the base station or determined by a distributed or random scheduling algorithm.

The integration of FDMA in protocol architecture brings several benefits. The most important one among these is that having as many nodes as possible to send and receive at the same time using different frequencies they increase the capacity of the data. Moreover, spreading techniques over multiple frequencies- eg frequency hopping, is an important method among others. In many nodes switching to alternative frequencies if experienced channel contention or on finding that another node is busy, the communication frequencies are smoothly changed that assists in mitigating collisions as well as management of channel utilization [5]. Figure 3.1 shows the taxonomy of WSN MAC protocols.

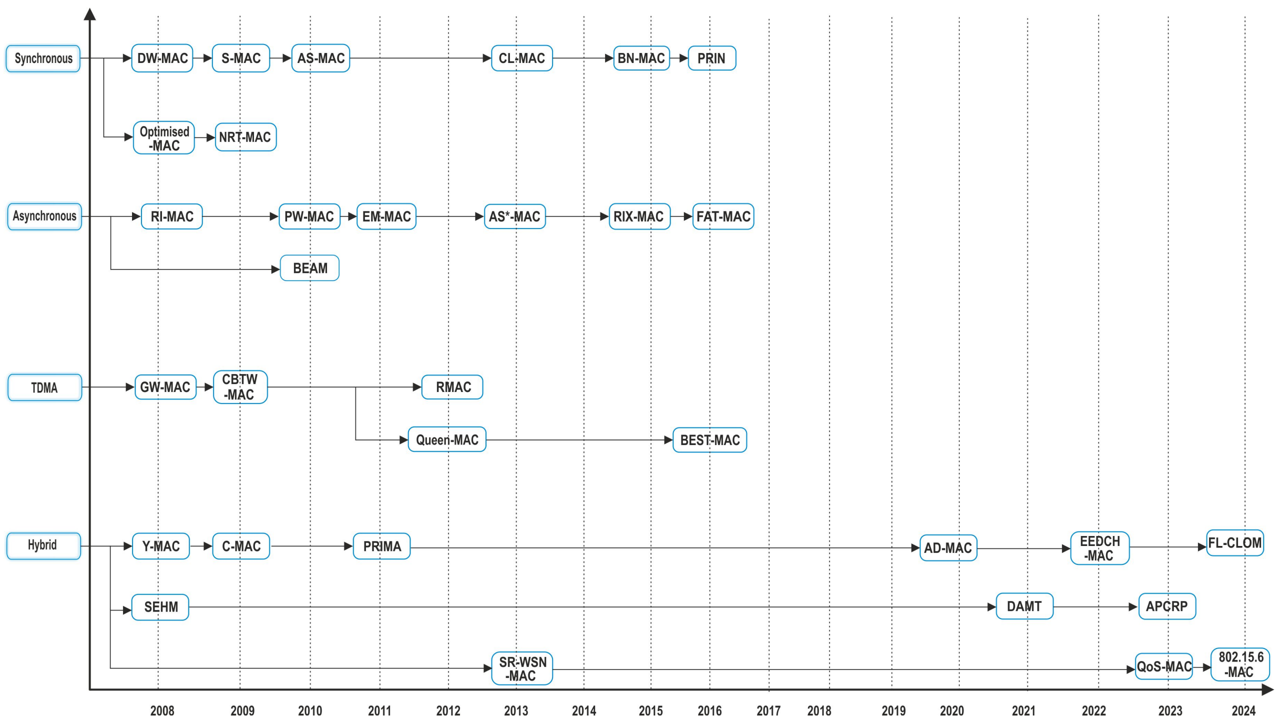

Figure 3.1: Taxonomy of WSN MAC protocols.

3.3 Literature Review

This section offers a brief description of a wide range of MAC protocols designed for sensor networks, focus on their essential behaviors wherever possible. It also outlines the advantages and disadvantages of these protocols. The survey reviews the most popular MAC protocols for WSN synchronous and asynchronous contention-based MAC protocols,TDMA-based MAC protocols and Hybrid MAC protocols, organized according to the taxonomy illustrated in Figure 3.1. Within these categories, the section discusses several typical protocols.

3.3.1 Synchronous Contention-based MAC protocols

This section provides a detailed examination of synchronous MAC protocols that employ a contention-based approach.

3.3.1.1 DEMAND WAKEUP MAC

DW-MAC is a synchronized duty cycle MAC protocol, where each cycle is divided into three periods : Sync, Data, and Sleep (Figure 3.2). We denote the duration of each period by TSync, TData, and TSleep, respectively. Similar to prior work, DW-MAC assumes that a separate protocol is used to synchronize the clocks in sensor nodes during the SYNC period with required precision.

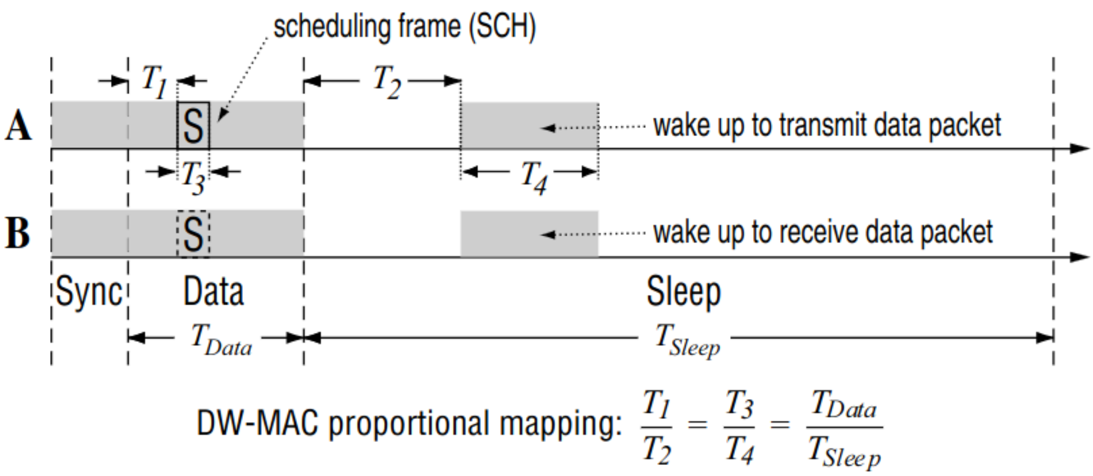

Figure 3.2: Overview of scheduling in DW-MAC

The basic concept of DW-MAC is to wake up nodes on demand during the Sleep period of a cycle in order to transmit or receive a packet.

This demand wakeup adaptively increases effective channel capacity during a cycle as traffic load increases, allowing DW-MAC to achieve low delivery latency under a wide range of traffic loads including both uni-cast and broadcast traffic.

DW-MAC is unique in the way it schedules nodes to wake up during the Sleep period of a cycle. In DW-MAC, MAC and scheduling are fully integrated. In a Data period, a node with pending data contends for channel access using a CSMA/CA protocol as in IEEE 802.11. DW-MAC, however, re-places RTS/CTS with a special frame called a scheduling frame(SCH). The interval of time during which the transmission of a SCH occupies the wireless medium automatically and uniquely reserves the proportional interval of time in the following Sleep period for transmitting and receiving the pending data packet. Essentially, DW-MAC sets up a one-to-one mapping between a Data period and the following Sleep period. An SCH carries no timing information, and the transmission of an SCH simply replaces that of RTS/CTS for MAC. In this way, DW-MAC minimizes scheduling overhead. As in an RTS, an SCH contains the destination address, so this SCH wakes up only the intended receiver, minimizing energy consumption due to unnecessary wake-ups.

Furthermore, this integration ensures that data transmissions do not collide at their intended receivers as discussed below. Figure 3.2 shows an overview of scheduling in DW-MAC based on this one-to-one mapping between a Data period and the following Sleep period.

In this example, node A wants to transmit a data packet to node B. Node A first contends for channel access and transmits an SCH during the Data period. Suppose transmission of the SCH starts T1 time units after the beginning of the Data period. Based on T1 and the duration of the SCH transmission, T3 ,nodes A and B will both schedule their wakeup time to T2 from the beginning of the following Sleep period, and will agree on a maximum wakeup duration of T4 , based on the ratio between TData and TSleep, as shown in the figure. If the packet to be transmitted is a uni-cast packet, node B will return a confirmation SCH frame (not in the figure) SIFS delay after receiving the request SCH from A ; if the packet is a broadcast packet, node B takes no further action. When nodes A and B both wake up at the agreed time, node A transmits the actual data packet, which can be either broadcast or uni-cast.

In case of uni-cast packet, node B acknowledges the successful receipt of the packet with an ACK. Although we show the scheduling for only one pair of nodes in this example,DW-MAC allows multiple contending nodes to exchange SCH frames with their intended receivers during a Data period, so that multiple data transmissions can happen in the following Sleep period [36].

3.3.1.2 OPTIMIZED MAC

The basic concept of Optimized MAC is to set a duty cycle based on the traffic load. Network load is based on the pending messages in a queue of the particular sensor node. This protocol adopted the synchronization process of S-MAC, using the same SYNC packet. However, data and control packets are modified such that SYNC and RTS are combined into SYNCRTS to reduce packets overhead and further reduction of energy consumption and latency. Each sensor keeps track of the traffic load based on the number of messages in its queue. Each time after receiving a packet node increases it packet counter to keep track of a number of the packet in its queue. If the number of messages exceeds a certain threshold, this node transmits SYNCRTS that contains its increased duty cycle. The nodes receiving SYNCRTS adjust its duty cycle accordingly.

Advantages : Consider the traffic load to adjust the duty cycle.

Disadvantages : Topology taken for simulation is not good to give the standard result. One node with more data will cause his neighbors to increase their respective duty cycle, which will increase the energy consumption and idle listening [5].

3.3.1.3 SENSOR MAC

Sensor MAC or S-MAC is one of the original MAC protocols for WSNs, which is based on a synchronous duty-cycled protocol. Energy efficiency is achieved by having a period duty cycle, by which a node will switch between active and sleeping periods during its lifetime. The duty cycle and duration of active and sleep periods are fixed throughout the lifetime, depending on the application requirement. Duty cycling in S-MAC is shown in Figure 3.3.

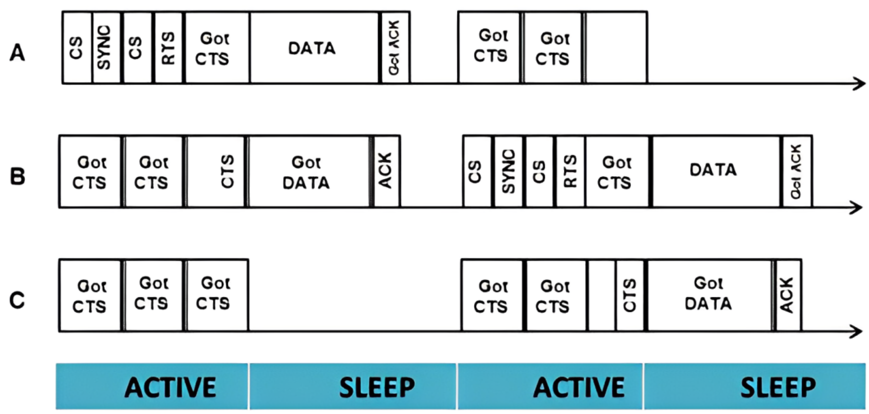

Figure 3.3: An example of duty-cycling in S-MAC, and data transmission from node A to node B followed by from node B to node C. [5]

In the SYNC period, a node waits for or broadcasts a SYNC packet, a short packet that contains the node's address and the node's next sleep time. Synchronization is done periodically to reduce clock drift among neighbouring nodes. Neighbouring nodes with the same schedules form a virtual cluster. S-MAC uses RTS/CTS handshaking mechanisms for data transmission to avoid a collision, overhearing and hidden terminal problems . It also uses a Network Allocation Vector (NAV), which records the transmission period for virtual carrier sense. A node which wants to send a packet transmits RTS to the destination node. Since the RTS packet contains the destination address, other nodes know that they may sleep during the SLEEP period.

Advantages : S-MAC introduces important concepts such as message passing, where long messages are divided into fragments and sent in a burst using RTS and CTS packets to reserve the medium for transmitting all fragments, and ACK for each fragment. However, this approach can lead to node fairness matters.

Disadvantages : The periodic sleep characteristic of S-MAC can result in high end-to-end latency, especially in multi-hop networks, due to sleep delay. Nodes at the boundary of two schedules must adopt both schedules, increasing energy consumption.

To address latency, Ye et al. introduced Adaptive Listening (S-MAC/AL) [37]. Nodes briefly wake up at the end of neighboring RTS/CTS transmissions. If one is on the next-hop path, it can immediately receive data. However, this can increase overhearing for other nodes and may reduce efficiency under variable traffic loads. Idle listening during no traffic can lead to energy waste, and synchronized schedules can cause high collisions during broadcast between nodes in a virtual cluster.

3.3.1.4 WAVE-MAC

Wave-MAC or W-MAC is a synchronous duty-cycled, contention-based protocol. W-MAC is designed for the event-driven and delay sensitive application in large-scale WSNs. W-MAC assumed that the sink is placed in the center of the network. It uses the S-MAC synchronization technique with some modification (SyncTag is added in the synchronous packet). An algorithm is proposed to perform the local and global synchronization. It utilizes the Future RTS (FRTS) . It assumes the DATA flow as unidirectional from sensor nodes to sink.The network field is organised by the concentric circles around the sink.

The difference between the two concentric circles is the transmission range of a node.The synchronization in W-MAC leads to the formation of Path-cluster and Waves. P-Cluster is limited to three consequent hops and a Wave consist of several consecutive P-Clusters. The number of P-Clusters at each Wave is directly related to the size of the network.

W-MAC assumes that the location information of each node in the network and sink is known. Each node in the network is assigned a NodeTag. The packet is always forwarded from a node to the same or lower NodeTag node and only these nodes are able to adjust their timer to wake-up and receive data [5].

Advantages : End to end delay and energy conservation is improved because of control packet overhead reduction and limiting the wake-up of overhearing nodes to same and lower hops node. W-MAC performance in low as well as high traffic is comparable with the S-MAC.

Disadvantages : However the network is divided into the cyclic concentric areas by utilizing the location information of nodes but this requires good localization algorithm to calculate the exact position of the nodes and big overhead in case of mobile nodes. In the case of heterogeneous transmission range, W-MAC will face several problems as one is dividing the network into concentric areas [5].

3.3.1.5 A NOVEL REAL-TIME MAC

A Novel Real-Time MAC or NRT-MAC is based on the idea of contention based protocol S-MAC. However, NRT-MAC uses a feedback approach as the medium access strategy, whereas S-MAC is a contention-based protocol that uses back-off schemes.The main aim of NRT-MAC is to be the best suited protocol for real-time WSNs, while several other real-time protocols like Virtual TDMA for Sensors (VTS), Implicit Earliest Deadline First (I-EDF), Path Oriented Real-time MAC (PR-MAC), Channel Reuse-based Smallest Latest-start-time First (CR-SLF) and TDMA based hard real-time MAC (RRMAC) are still into existence.Figure 3.4 shows the functioning of NRT-MAC.

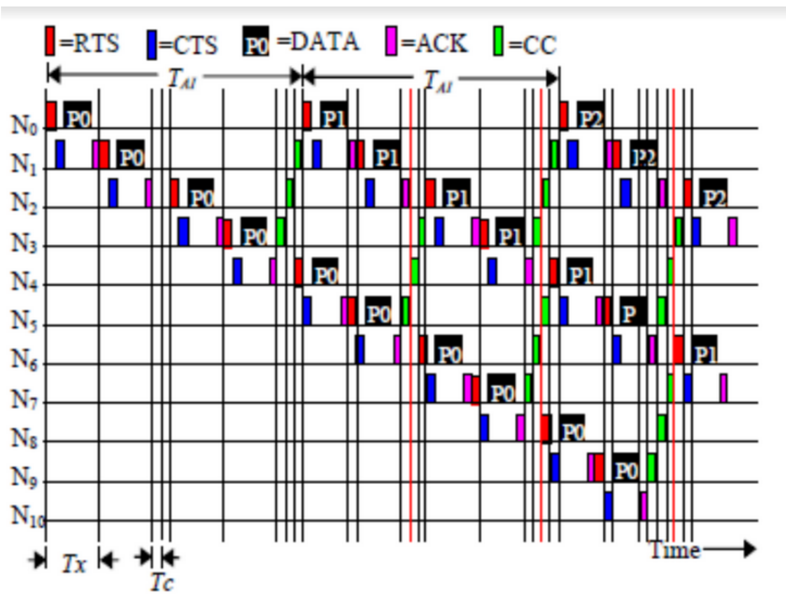

Figure 3.4: The timing diagram of packet transfer in NRT-MAC

NRT-MAC uses RTS_CTS like the 802.11 and S-MAC to deal with the hidden terminal problem. It uses the feedback control packet called Clear Channel (CC) to remove the uncertainty of winning the channel among the several nodes wishing to send the data packet. This control packet CC is used to assign a Boolean value to Clear Channel Flag (CCF) and has a Clear Channel Counter (CCC) with an integer value range from 0 to 3. DATA transfer cycle duration is designated by Tx and the duration of one control packet is designated by Tc.

Advantages : Guaranteed lesser end-to-end delay and packet transfer delay for the soft real-time application. Contention and collision are less because of the feedback medium access strategy used in the protocol.

Disadvantages : The delay is less in the NRT-MAC, but the control packet overhead is very high. The protocol only considers one source and one destination and is not scalable during the lifetime of the communication stream in randomly deployed WSNs [5].

3.3.1.6 AS-MAC

An Adaptive Scheduling MAC (AS-MAC) protocol is proposed to make nodes' active duration adaptive to traffic load. Specifically, when the traffic load is high, AS-MAC can achieve rapid data dissemination and reduce transmission latency by scheduling more transmission. In addition, when the traffic load is light, nodes switch to a sleeping mode in a timely manner, such that idle listening is mitigated and energy conservation is achieved. Evolving from DW-MAC , AS-MAC also makes sensor nodes wake up on demand to transmit or receive data packets. However, different from DW-MAC, AS-MAC makes use of the AS period to replace the Data period, so that the active time can be adaptively changed.AS-MAC introduces a flexible Reserved Active Time (RAT) within the AS period. The length of RAT has changed adaptively to variable traffic load. A timer is designed for a node to determine the necessity of entering sleep mode. Figure 16 shows that in each operation cycle, the length of Random Access Region (RAR) is adaptively changed with a different number of events (traffic load).

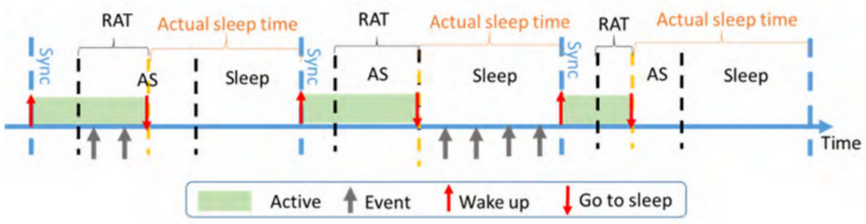

Figure 3.5: The reserved active time is adaptively changed in AS-MAC.

In addition, to solve the problem of delay of scheduled transmission and prevent duplicate packet transmission, AS-MAC introduces two new parameters in the SCH,i.e., RTS_RetryNo and CTS_RetryNo. With the help of these two parameters, whether or not the distinct SCH transmission is successful can be determined, so as to avoid duplicate packet transmission.

Advantages : Under high traffic load, AS-MAC allows more data transmission in one operational cycle, while the data transmission is resiliently scheduled in the sleep period. AS-MAC can achieve the goal of energy saving and reduction on latency by successfully mitigating the duplicated data transmission and idle listening, respectively.

Disadvantages : In order to enhance the broadcast performance, AS-MAC prevents nodes at different locations from entering sleep mode early by adjusting the timeout duration. Specifically, the farther a sensor node locates away from the sink, the longer timeout duration that node needs to wait. Although this scheme can achieve shorter latency, more energy will be consumed, especially when the network size is large.

3.3.1.7 CL-MAC

The design of CL-MAC is aimed at enhancing multi-flow and multi-hop transmission, so it can be used for low latency, improved Packet Delivery Ratio (PDR), and less energy consumption per packet delivery. CL-MAC takes into consideration the pending packets from the routing layer as well as flow requests from neighboring nodes when deciding on a flow. Communication is set up by sending Flow Setup Packets (FSPs), whose length depends on the number of packets, flows, and receivers. FSP is an RTS packet for the destination node and a CTS packet for the source node in their scheme.When a node has packets for different destinations with different next-hop forwarders, it forwards the FSP with priority indications to those forwarders. Nodes receive the FSP and reserve time slots as per the specified priority. To provide fairness in channel access, CL-MAC also incorporates the Network Allocation Vector (NAV), which grants longer waiting times for nodes that are closer to their destination. With regard to flow establishment, CL-MAC allows a single node to send many flows over several hops through each frame [5].

Advantages : CL-MAC can effectively exploit the utilization of sleep period with the design of FSP. In a single wake-up cycle, a node can schedule multiple flows for multiple destinations through multi-hop data forwarding, which results in a significant reduction of latency and improvement of throughput.

Disadvantages : The length of FSPs messages depends on several factors. With an increase in a number of flows, packets, and receivers, the length of the FSP message also increases, which results in significant overhead. This over-head leads to increased energy consumption in the network.

3.3.1.8 BN-MAC

An energy-efficient, low-duty-cycle, and mobility-based Border Node-MAC (BN-MAC) protocol are proposed in [38] to achieve low latency, energy conservation, and enhanced throughput while supporting mobility and scalability. The network is segmented into regions, each with a Border Node (BN) that relays data from nodes inside the region to outside. The dynamic BN selection process (DBNSP) model selects BNs based on residual energy, memory allocation, and signal strength. BN-MAC operates in three phases :

1. **Topology Setup Phase** : Nodes maintain a principal node and a backup node among one-hop neighbors for data forwarding.
2. **Intra-Semi-Synchronized Communication Phase** : Nodes synchronize with either the principal or backup node using a short preamble message.
3. **Inter-Synchronized Communication Phase** : BNs send HELLO messages to wake up neighbors and transmit a Border Node Indication Signal (BNIS) to communicate the transmission schedule.

The protocol eliminates idle listening using the Idle Listening Control (ILC) model, where nodes enter sleep mode when a timer times out, conserving energy.

Advantages

- Utilizes a low duty cycle and introduces a semi-synchronization approach.
- Dynamic selection of BN improves the network lifetime significantly.

Disadvantages

- The selection of BN requires the exchange of control messages, resulting in additional energy consumption.
- If a BN's energy depletes or it moves out of the region, all nodes inside that region suffer from communication failure.

3.3.1.9 PRIN

A QoS protocol, i.e., a priority-based energy-efficient MAC protocol, namely PRIN, is proposed for WSNs [39]. PRIN uses two kinds of priorities. Nodes that are closed to the source node are given high priority. The priority of nodes is decreasing towards the receiver.

Furthermore, PRIN makes use of priority queues for data with different QoS requirements. In PRIN, the packet arrival is considered as three processes, i.e., inter-arrival process, retrial process, and services process, which are independent of each other. Once an event occurs in the network, the classifier of a node identifies the priority of the data. If the size of a queue is MAX, the sample inter-arrival rate of data varies. In addition, re-transmission is applied to provide reliable data delivery. When the data cannot be successfully delivered and the number of re-transmission reaches the maximum limit, that data is discarded from the queue. In addition, to avoid packet collision, a back-off time is randomly chosen. Furthermore, successful transmission is acknowledged by ACK [5].

Advantages : PRIN can achieve high throughput with reduced latency by varying the inter-arrival rate.

Disadvantages : Under interference, PRIN cannot achieve better throughput, compared to S-MAC [40] and T-MAC [41]. PRIN needs to be modified to reduce packet loss due to interference.

3.3.2 Asynchronous Contention-based MAC protocols

3.3.2.1 RI-MAC

Receiver-Initiated MAC (RI-MAC) aims to maximize channel utilization and reduce listen-only time by perfectly managing data exchange between sender and receiver [42]. In RI-MAC, the receiver can wake up from time to time based on its certain schedule and send the beacon to see if there're incoming DATA packets or not. When the beacon is received, the sender transmits over the channel the corresponding DATA packet to the receiver in the first place. Then, the receiver announces having processed the former packet by means of a new beacon, thus enabling the additional DATA packages to be sent. Nevertheless, these collisions might surface as a result of the sender nodes performing transmission of DATA packets simultaneously. For this aim, RI-MAC uses a mechanism of collision handling with a large data broadcasting time window such as a beacon (Figure 3.6).

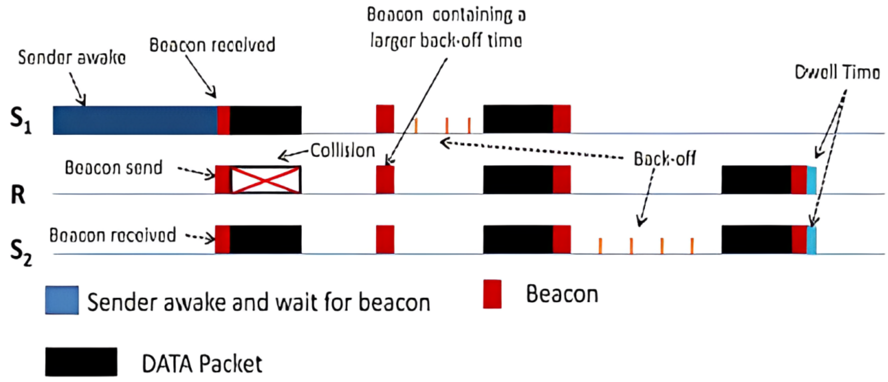

Figure 3.6: DATA transmission from contending senders in RI-MAC. [5]

Nodes in RI-MAC have remain awaken for a require period of time which known as Dwell time that helps the queued packets to be received. The pace of music relates to how many people give their input. Moreover the Participate in Beacon mode is manually initiated when the undone transmission of data frame is pending.

Advantages : RI-MAC then focus on numerous advantages over X-MAC especially in scenarios when the traffic fluctuates. That shows leading in the capacity of packet throughput, packet delivery ratio and endurance to power.

Furthermore, courtesy of the sender based technology, the application becomes an efficient tool, therefore, in the data recovery process and collision avoidance [5].

3.3.2.2 BEAM

BEAM (Burst-aware Energy-efficient Adaptive MAC) [43] can be considered as an alternative to solve the matter of latency, efficiency and reliability of data delivery while saving the energy at the mean time. Extended Adaptation algorithm , based on BEAM, enables sleep time selection, depending on sizes of the payloads, in order to continue with heterogeneous transmission schedule. Two operational modes of BEAM are shown by this transmitting data with or without payload can be performed by preambles.

In the standard operation mode, short preambles are often engaged with payload by the sender periodically. The destination address is the first thing the receiver reviews once waking up to determine if it is for him/her. The sending device enters sleep mode after the ACK is received for the data (Figure 3.7).

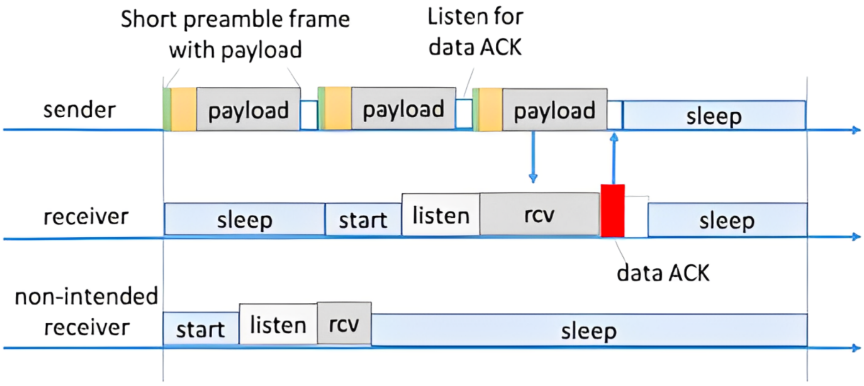

Figure 3.7: BEAM using Short Preambles with Payload. [5]

On the other hand in the second case, the sender sends short preamble without payload until the regarded addressee acknowledges; afterwards the data frame with payload is transmitted (Figure 3.8).

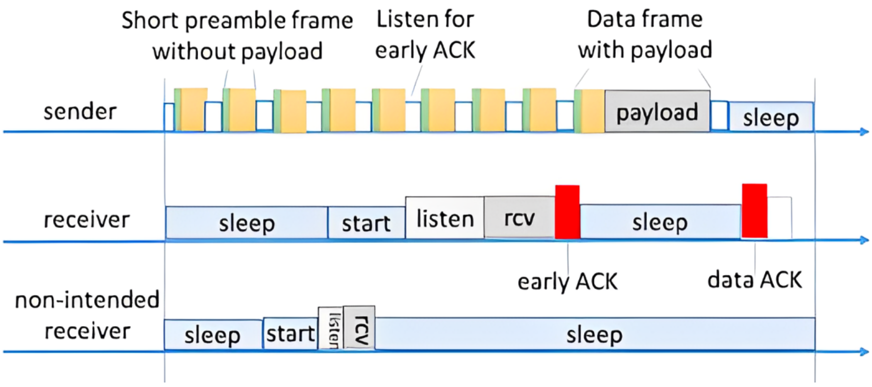

Figure 3.8: BEAM using Short Preambles without Payload. [5]

Advantages : BEAM pros consist of decreased time of overhearing by non-intended receivers therefore, the timely gateway into the sleep mode can be realized hence energy conservation is enhanced. The protocol will dynamically switch between modes in order to adjust the payload and hence, optimize the energy consumption. Besides, BEAM promotes hop- to-hop reliable data delivery by using an acknowledgment mechanism.

Disadvantages : Nevertheless, the broadcasting nature of transmitting the preamble frame void of a payload takes at least four transmissions, making it more complex and less reliable compared to the already agreed basic transmission modes. [5]

3.3.2.3 PW-MAC

The Predictive-Wake up MAC (PW-MAC) [44] protocol having the function of avoiding the stable idle state and reducing the energy use of nodes is formulated by the reaching senders to receiver's waking up time. The nodes waking times are attributed to a unique software program installed in the device. The next node of the network is activated every now and then in order to send a beacon signal for its neighboring nodes as a readiness to interact with fresh data records. Through the process of decoding of the information embedded in the parameters, a transmission of instant data from the sender to the receiver is triggered just before the receiver wakes up.

PW-MAC uses prediction for re transmission-based reliable data delivery and low latency. On detection of collision, the node slips into a sleep mode and wake up only when a predicted interaction is established. As ACKs for previously transmitted data packets do not come from the erroneous receivers, yet wake-up beacons from the receivers do, the senders can achieve locating collisions. They now down to sleep mode and wake up at the specific current receiver wake-up time for down linking.

Advantages : The technical advantages of PW-MAC may be summarized as the deterministic wake-up time of the receiver therefore collision is avoided.

Disadvantages : On the one hand, the protocol highly raises the communication packet overhead as nodes render packets even in an idle zone. The high connection density networks may exacerbate such problems, which may be caused by periodic transmission of pseudo random generator parameters. [5]

3.3.2.4 EM-MAC

The Efficient Multichannel MAC (EM-MAC) [45] is a protocol that chooses the most appropriate wireless channels based on the real data about channel status and aims to improve channel utilization and transmission efficiency. EM-MAC is an articulated foretelling of the probability of the active link getting constantly interrupted by interferences resulting from an improperly employed multiple orthogonal channels otherwise used to avoid busy channels. To begin with, the different methodology between EM-MAC and the few protocols are that EM-MAC never uses the control channel for the meeting delivery.

Each node individually will wake up, do the switch, and choose its broadcast channel using a random number function. Nodes will migrate the wake-up beacon to potential receivers, which is used by the senders to predict the receivers' waking time and channels based on the beacon information. When the time comes, therefore, the senders become used to getting up just before the receiver and encoding only those that are part of the channel. Receivers guarantee reception of the successful packets by also sending acknowledgements.

An example of a sender S sends data to sender R is shown in Figure 3.9.

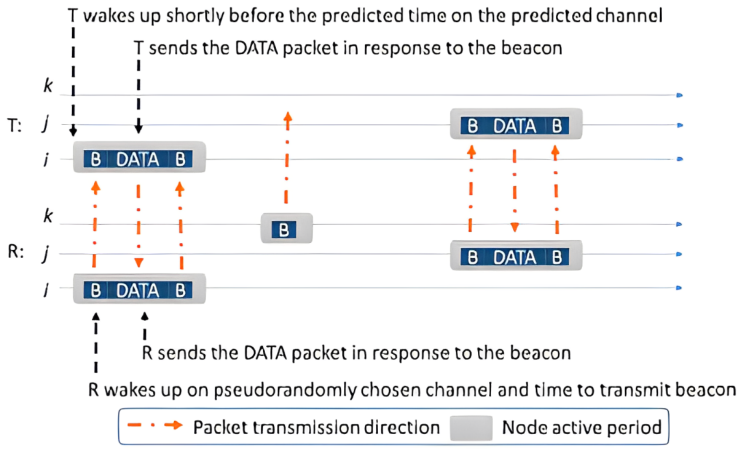

Figure 3.9: DATA transmission in EM-MAC. [5]

Advantages : Among the many advantages of EM-MAC are its robustness against wireless interference, trouble-free handling of dynamic loads, low delay time, and high reliability of data delivery. The multi-channel-based EM-MAC protocol shows some clear advantages over single-channel architectures, primarily in the case of time-varying channels and their effect on performance indicators.

Disadvantages : Nonetheless, EM-MAC brings protocol overhead along with every node's necessity to send a beacon each time it turns on. Lastly, the waking channel and time calculation algorithm invoke the pseudo random generator twice, which could bloat the overhead big time with time. [5]

3.3.2.5 AS-MAC*

The AS-MAC* protocol, designed for the cases of asynchronous scheduled WSN MAC (AS-MAC*) [46], allows for the storage of the schedules of the neighbor nodes, consequently enabling the asynchronous wake-up in order to avoid possible interference. When the nodes are coming to life, every node records a neighbor table, including the scheduling data of its neighbors. The nodes simultaneously enter the asleep and listening phases, waking up after a short while of their neighbors to be capable of sharing information.

AS-MAC* achieves compensation for in-flight data loss by sending an ACK message upon correct data reception. After sending a data packet, the sender starts a timer. The timer measures the duration from sending the packet to receiving an ACK. In the absence of acknowledgement within a specified time, the sender will slip into sleep mode, where it will re-transmit the data at the next wake-up time. The transmission will happen with the back-off algorithm, where the maximum number of re-transmissions is limited.

Advantages : Advantages of AS-MAC* include inheriting existing MAC protocol advantages while adding energy-saving features. It mitigates overhearing, reduces channel contention and latency for data delivery with asynchronous neighbor node wake-up schedules.

Disadvantages : However, AS-MAC* suffers from broadcast inefficiency due to asynchronous wake-up intervals, requiring individual data transmission to each neighbor. Additionally, maintaining a one-hop neighbor table results in overhead and increased memory usage. [5]

3.3.2.6 RIX-MAC

The wake-up scheduling scheme implemented in the RIX-MAC [47] scheme (a new version of X-MAC [48]) reduces the number of control frame transmissions and the clearing of collisions. Similar to RI-MAC [42], RIX-MAC cuts incoming traffic from control packets and supports several senders and a common receiver.

In RIX-MAC, the senders estimate the receiver wake-up times to wake them up just before. The extra fields in the control packet contain the awakening signal and the duration of the transmission. With this data, senders wake up twice per cycle : first for data reception and, consequently, for transmission.

Collisions happen when at least two senders send data to the same receiver. RIX-MAC tackles this by having sending nodes wait randomly in-between wake-up times.

Advantages : Benefits that are specified in short preambles include sender-receiver wake-up time prediction and collision avoidance due to back-off times.

Disadvantages : Nevertheless, RIX-MAC demands node synchronization with clock adjustments from time to time, causing time overheads and energy consumption. [5]

3.3.2.7 FTA-MAC

The FTA-MAC protocol [49] is used as a condition for pace adjustment at the receiver side instead of data rate ; the protocol thus results in energy efficiency by adjusting the wake-up duration. Using TSR technology (Traffic Status Register [50]), vehicles are able to encode packets that contain no data while marking a TSR bit for traffic after the traffic has been established.

In network convergence, senders keep periodic wake-up beacons for aspects of wake-up time synchronization with their neighbors. Then, sleep senders activate with their broadcast requests and wait for the beacon to take in more data. Moving forward, the sync-up will be followed by wake-up intervals for the receivers determined by the TSR period to minimize the listening idle time.

Advantages : Firstly, there are benefits, which include instantaneous synchronization with the wake-up time and the elimination of energy waste, which is done by powering off the utilization of resources.

Disadvantages : However, the FTA-MAC may also unite to incorrect TSR values, and then the message will be missed by neighbors, leading to conflict or even discarding the message. As well, we are free from strain or stochasticity in traffic conditions, and network topologies designed as star-topologies do experience problems of multi-hop. [5]

3.3.3 TDMA-Based MAC protocols

3.3.3.1 GlacsWeb MAC

GW-MAC [51] is a time division multiple access (TDMA-based) MAC protocol designed for very unfriendly glacial environments where wireless communication of sensor nodes fails. In this protocol, nodes can have a sleeping state where they can stay dormant for a period ; such nodes wake up for communicating or sensing activities.

Time regulation in GW-MAC is achieved through time frames and slots, and the base station is responsible for slot assignment. The network configuration and discovery processes depend on a regular basis to ensure optimal slot assignment and network efficiency optimization. Each node that does not require active transmission is set to listen-only mode to avoid disruption. Figure 3.10 shows a network after configuration.

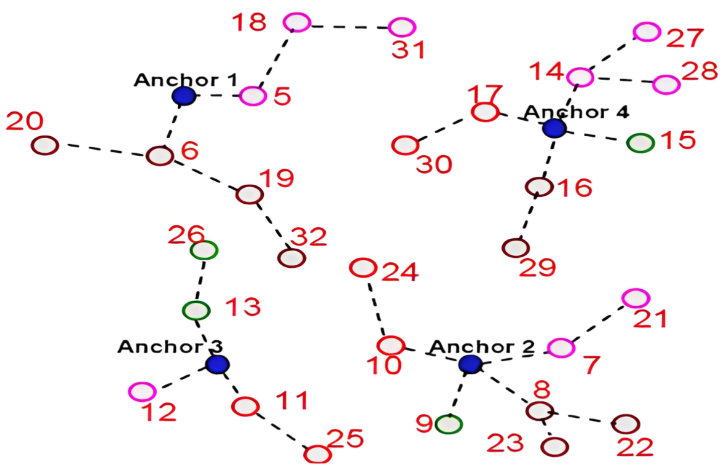

Figure 3.10: Network after configuration. [5]

Advantages : GW-MAC has the ability to function in remote areas, consume a minimal amount of energy because the wake-up time of the nodes is diminished, and also use looper communication frames more effectively.

Disadvantages : Although GW-MAC introduces solutions for connecting wireless sensors to networks, it does not provide a general-purpose MAC protocol and requires both the deployment of wired anchors and wireless nodes, which creates a high deployment cost. [5]

3.3.3.2 CBTW

CBTW is a distributed, clustering-based protocol with intra-cluster coverage. It is based on the existing Time Division Multiple Access Wake Up (TDMA-W) protocol. The idea is to utilize assigned slots in the nodes only for receiving and transmitting the DATA ; otherwise, keep the radio off to avoid idle listening. Wakeup packets are used to activate the sleeping nodes, accelerating the receive response. CBTW operations are divided into rounds. Each round in the protocol includes :

1. Set-up phase, clusters are organized with the selection of cluster head nodes (intra-cluster coverage) and routing trees are constructed.
2. Working phase : data gathering from the nodes to base stations takes place.

CBTW uses TDMA-W for intra-cluster communication and TDMA schedule for inter-cluster communication. Each node in the cluster send its corresponding DATA to the cluster head in its assigned slot, then cluster head sends this DATA to the sink by the TDMA-W method.

Advantages : Data aggregation in the cluster head and packet passing from cluster to cluster head can reduce the duplicate packet overhead and data traffic.

DisAdvantages : Cluster formation is an overhead and even one cluster failure during data transmission can cause severe packet loss and overhead. Latency is high and hence not suitable for event-driven applications. Tree formation is difficult in frequently changing network scenarios [5].

3.3.3.3 RMAC

Receiver-Driven MAC (RMAC) [52] is a TDMA approach to provide collision-free transmissions. RMAC is composed of three stages, i.e., neighbor discovery, timeslot allocation, and scheduled transmission.During the neighbor discovery stage, each node maintains a two-hop neighbor table. Nodes within two-hop will not be assigned to the same timeslot. During the data transmission phase, receivers only wake up and listen to the channel during the time slots assigned to them. For the rest of timeslots, receivers remain asleep. The assignment of time slots is based on the distributed scheduling solution (DRAND) [53].

RMAC introduces timeslot stealing mechanism to enable other senders to use the unused timeslots. For each times lot, there is a primary sender node and secondary sender node assigned. The secondary sender node listens to the channel to determine whether the primary sender node is occupying the channel or not.

Advantages : In RMAC, receiver nodes assign the times-lots to their sender nodes, thus eliminating possible channel contention and packet collision. With the timeslot stealing mechanism, the channel utilization is increased and latency for packet delivery is reduced.

Disadvantages : In RMAC, whenever the topology of the network changes, neighbour discovery and timeslot allocation need to be performed. This requires the exchange of HELLO messages resulting in considerable overhead and energy consumption. In addition, the time slot stealing increases energy consumption as a secondary sender needs to listen to the channel.

3.3.3.4 QUEEN-MAC

Queen-MAC [54] is the adaptive and energy-efficient MAC protocol, which is applied for DGS (Dyadic grid quorum systems), where sensors are alike and at the same distance and the sink node is at the corner. The protocol assumes time synchronization across all sensors when quorum timeslots and non-quorum timeslots occur.

While during quorum timeslots, the nodes are supposed to be awake for message exchange, they go into sleep mode during non-quorum times to save energy. Queen-MAC utilizes their algorithm, which schedules the timeslots only for the node exchange with required data and adjusts the wakeup frequency according to the traffic load to benefit power savings.

Moreover, the Queen-MAC has several channels for simultaneous signal transferring, where every node is assigned specific frequencies in order to avoid interference. On the other hand, the problem with layer one is that it does not handle the collision of packets, thus resulting in silencing the wireless channel and having an undesirable effect on the number of delivered packets.

Advantages : It supports multi-channel access and schedules node sleep and wake-up terms, and the whole network duration was demonstrated by simulations and theoretical analysis.

Disadvantages : Fails to consider packet collisions, which leads to higher packet loss ;

sink nodes get overloaded with data traffic and may saturate to reduce performance [5].

3.3.3.5 BEST-MAC

The proposed BEST-MAC protocol [55] designed for the cluster-based WSNs, to serve different priorities with the consequences of very low delay and significant power savings, is the Bitmap-assisted Efficient and Scalable TDMA-based MAC protocol . BEST-MAC employs a two-phase framework where these are the Set-Up Phase (SP) serving as the preparation phase and Steady State Phase (SSP) set to be the implementation phase.

During SP, the Cluster Head (CH) normally calls for a resource within member nodes to assign them slots of time in which the information packets may be sent using a CS_ALLOC message. SSP operation is done using a session structure which has a control slot, periodic Contention Access Period (CAP), and multiple data slots. Moreover, BEST-MAC comes up with mini time slots so as to minimize queueing time and increase the current throughput which is done through knapsack algorithm which in turn optimizes channel slot allocation to enhance the efficiency and reduce the delay [5].

Advantages : BEST-MAC offers the flexibility to accommodate transportation load condition period. It also saves the energy since transmitter node only has a short address.

Disadvantages : Nevertheless, it is confronted with control messages excesses and cell heads dependent on time slots which disintegration the data stream if CH had been scattered. [5]

3.3.4 Hybrid MAC protocols

3.3.4.1 C-MAC

C-MAC is designed to exploit concurrent wireless channel access according to the empirical power control and the physical interference model. It is designed to achieve high-throughput in high traffic scenarios for data-intensive sensing applications.

C-MAC utilizes the transitional relationship between the Signal-to-Interference-plus-Noise-Ratio (SINR) to the Packet Reception Ratio (PRR) and enables concurrent transmission of sensor nodes even though they are within the each other's interference range. It chooses the transmission power such that it will maximize the total throughput of active links. Figure 3.11 shows a complete process of data block transmission in the transmission engine.

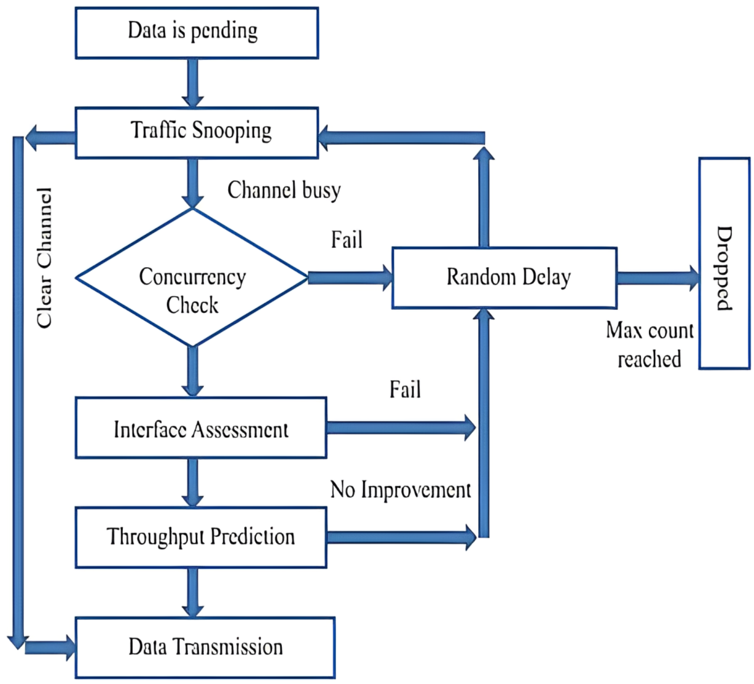

Figure 3.11: A complete procedure of transmitting a data block in the concurrent transmission engine. [5]

C-MAC has the following components (3.11). First, online model estimation is used to periodically estimate the power control and interference models. Second, traffic snooping is used to snoop the ongoing traffic to identify the transmission links. Third, the concurrency check is used to check if the pending data block is transmitted simultaneously with the ongoing traffic according to the interference models.

Fourth, interference assessment is used to avoid the primary interference caused by two nodes, which are intended to send the data to the same receiver and for obtaining the interference level information at the intended receiver, which enabling link estimation. Fifth, throughput prediction is used to get the estimated throughput of concurrently transmitting link and sixth, concurrent transmission engine is the most important part of the C-MAC as it coordinates with the other components during their operations. C-MAC performs one traffic snooping and exchange of RTS/CTS for a block of the packet, while the clear channel assessment (CCA) which was used in B-MAC to sense the channel is completely removed. C-MAC is compared with B-MAC while the sleep mode is disabled in B-MAC to gain high-throughput when nodes are actively communicating.

C-MAC performs well as compared to the B-MAC in terms of throughput, delay, and energy consumption.

Advantages : C-MAC is reliable in data-intensive sensing applications. Dynamic power adjustment of the transmitter according to the level of interference of the channel improves the throughput and energy efficiency of the network for high data traffic. C-MAC block-based communication mode enables multiple nodes to transmit concurrently within the interference range of each other and reduces the overhead of channel assessment.

Disadvantages : C-MAC obtains high-throughput by not letting the node sleep, resulting in high energy consumption and is not suitable for low data traffic.

3.3.4.2 SEHM

Smart Energy Harvesting Medium Access Protocol (SEHM) [56] is hybrid MAC protocol for large-scale deployment of WSNs. The protocol combines contest-based and scheduling run-time mechanisms, which leads to high energy efficiency and improved throughput.The protocol operates in two main phases : cluster formation and data transfer. CHs are proposed in a clustered structure by the Ext-HEED algorithm, where residual energy and communication costs are considered based on the selection. SEHM's clustering algorithm involves four phases : starting with initializing, following on with repetition, getting to the optimization, and ending with finalizing.While the data transmission, CHs manage cluster channel access and send data to the BS. Intra-Cluster flow processes consist of a synchronized procedure in which a request is initiated, followed by a response, and then the transfer of data. Intra-cluster communication involves coordinating and receiving schedules and data transmission periods.In SEHM, specifically, energy efficiency is high and collisions are not because the TDMA, which is designed to avoid collisions, is used, but the average delay is really high because time division is applied in data transmission in general. Moreover, the layering of clustering algorithms as well as the synchronizing process add to the cryptographic MAC protocol for use at the SEHM level.

Advantages : almost zero energy consumption TDMA traffic ensures efficient data transfer through the channel that avoids collisions as packets are transmitted individually.

Disadvantages : An average transmission delay time increased in the case of TDMA clustering in overload situations, and it also led to a rise in extra tasks in clustering algorithms and synchronization [5].

3.3.4.3 PRIMA

PRIMA (Priority-based MAC Protocol) [57] is no more than an energy-efficient MAC protocol performing routing function in WSNs based on the Q-MAC protocol [58]. It is divided into two main phases : clumping and access channelisation aiming for scalability and sustainable usage of the network energy.

The clustering stage uses a variant of LEACH [59], which gives our Cluster Headers (CHs) a probability p for selecting CHs, which contributes to the workload balancing and energy conservation through CH role rotation. A CH maintains its position for a certain period of time. It is removed from the network and then another CH is chosen in its place.PRIMA is formed by the Classifier MAC and the Channel Access MAC combines both TDMA and CSMA specially. Packets are put into different priority queues, which process them by their relative importance.

In (WSN), intra cluster communication is supported by cluster heads broadcasting schedules to the network nodes. At the same time, communication between CHs and the Base Station (BS) involves distribution of schedules from BS to CHs assuming all CHs have data that require transmission through the BS.

Figure 3.12 is the PRIMA Functional Diagram.

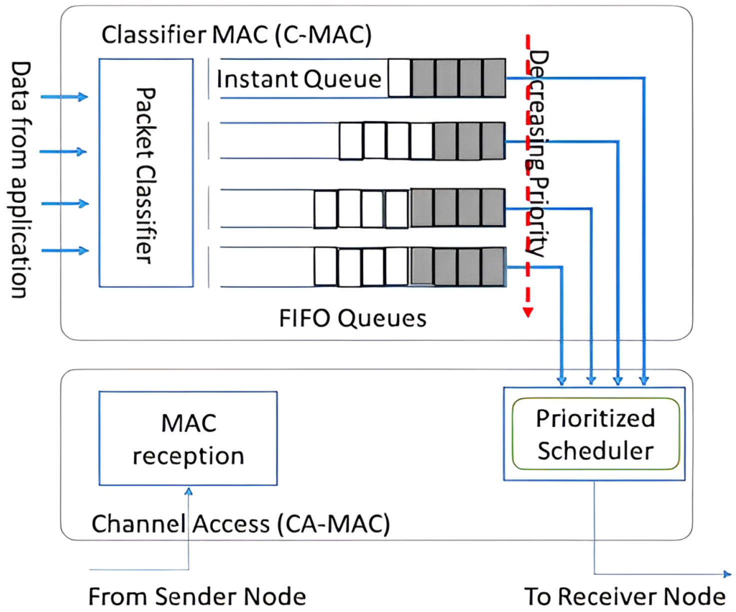

Figure 3.12: PRIMA Functional [5].

Advantages : Through the combination of contention and scheduled-based protocols, the energy conservation is greatly achieved ; by the incorporation of priority queues, QoS for different traffic types under different conditions are guaranteed, hence, less latency time for high-priority packets are expected.

Disadvantages : See the skyrocketing costs of overhead and energy required by the BS for the topology understanding to schedule the transmission slots, power depletion is more significant as the number of nodes becomes larger [5].

3.3.4.4 CR-WSN MAC

Cognitive Radio-enabled (CR-WSN MAC) [60] is a forward-thinking multi-channel asynchronous MAC protocol that employs spectrum-awareness technology and is suitable for WSNs with this technology. It employs the cognitive radio technique to gain the channels in an advantageous fashion by chance, which happens to be the reason for decreased congestion and low bit error rates for data delivery.The network in CR-WSN MAC manages two types of users : Primary Users (PU), who are the original network users, and secondary users (SU). The network provides data channels for SU and a control channel for optimizing resources. PUs are given leased channels, whereas SUs coordinate the use of data channels when they aren't occupied by PUs by adhering to an asynchronous duty cycle.

CR-WSN MAC operates in three phases : spectrum sensing, channel negotiation, and data transmission. It simply adopts brief preambles that contain destination node addresses for the purpose of energy conservation by giving non-destination nodes permission to switch to sleep mode immediately after receiving the preambles.

Advantages : use the cognitive technology to reduce idle listening and work without synchronized networks. That's why it is capable of reliable data delivery, though it rotates using its available data channels.

Disadvantages : Enlarged data unit size bears the risk of multiple PUs throttling the medium to get precedence, which will consequently lead to a decrease in throughput [5].

3.3.4.5 EEDCH-MAC

The Energy-Efficient Duty Cycle Hybrid MAC Protocol (EEDCHMAC) begins with a setup phase similar to those in TDMA, EA-TDMA, BMA, E-BMA, ABMA, ASH-MAC, and EEHMAC protocols. Following this, the post-setup phase categorizes sensing devices into constant-checking and incident-focused devices. As shown in Figure 3.14, in the data transmission phase, each session is divided into two sub-slots : sub-slot-1, where constant-checking devices transmit data , and sub-slot-2, where incident-focused devices transmit data using a unique duty cycle method with a bit-map-assisted MAC protocol (DC-BMA). During the entire contention period, non-source devices remain in a sleep state, while source devices broadcast a two-bit buffer status to the cluster head. This method allows for precise control over the trans-receiver radio's on/off times, optimizing energy consumption. Although increasing the bit status reduces quantization error and improves control, it also raises the transmission bandwidth for control packets. The protocol currently uses a 2-bit status, which can be adjusted according to application needs [61].

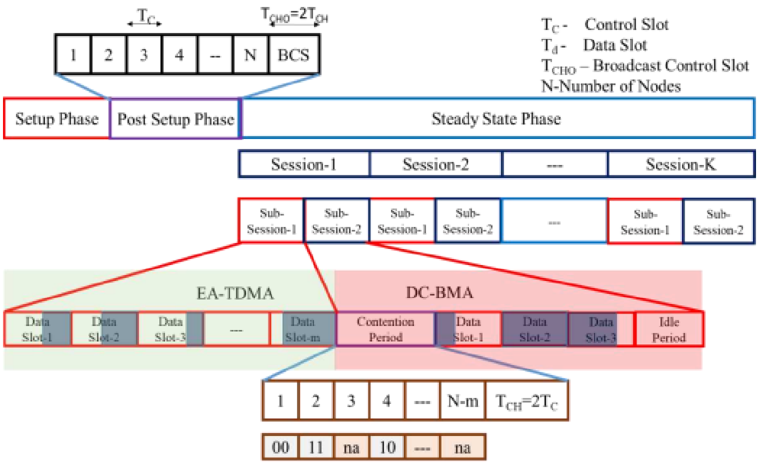

Figure 3.13: Operational Diagram of EEDCHMAC

Advantages : The control of trans-receiver radio on/off times, minimizes energy wastage by ensuring that non-source devices remain in a sleep state during contention periods, reducing unnecessary power consumption.

Disadvantages : the mechanism may lead to increased transmission bandwidth for control packets with higher bit statuses, potentially affecting overall network efficiency. Additionally, managing different sub-slots and categories of devices could introduce complexity, requiring careful coordination and implementation to ensure smooth operation.

3.3.4.6 DAMT

The Dynamic Adaptation Mechanism for Traffic (DAMT) protocol offers several advantages for WSNs. It dynamically adapts to varying traffic conditions, prioritizing high-traffic emergency nodes for immediate access to the medium and efficiently allocating Guaranteed Time Slot (GTS) slots for normal nodes. This dynamic adjustment helps optimize energy consumption by minimizing unnecessary waiting times and collisions, thus improving overall network efficiency. Additionally, the protocol's use of fuzzy logic for backoff exponent adjustment allows for a more intelligent and adaptive approach to traffic management, enhancing the network's ability to handle fluctuating traffic loads [62].

Advantages : DAMT optimizes energy use and network performance by dynamically adjusting to traffic fluctuations. It prioritizes high-traffic emergency nodes for swift medium access, enhancing overall network efficiency.

Disadvantages : The protocol's complexity in managing dynamic parameter adjustments can increase implementation overhead. Prioritizing high-traffic emergency nodes may lead to fairness matters, causing delays or reduced access for normal nodes [62].

3.3.4.7 AD-MAC

AD-MAC (Adaptive Duty-cycle-based Hybrid MAC) is designed for cluster-based wireless sensor networks (WSNs). Time in AD-MAC is divided into frames, each with active and sleep periods. The active period further divides into phases, with clusters distributed among these phases. Cluster heads (CHs) follow a periodic active/sleep schedule, and nodes in a cluster follow their CH's schedule using different frequencies. Each phase's schedule is skewed in time compared to other phases, ensuring non-overlapping active periods for CHs in different phases. This approach reduces energy consumption as nodes only wake up during their assigned phase. CHs use Time Division Multiple Access (TDMA), while member nodes use Frequency Division Multiple Access (FDMA) for channel access [63] (see Figure 3.14).

Advantages : AD-MAC requires less energy compared to S-MAC due to reduced listen periods. New nodes joining the network are added to a cluster and follow the CH's schedule, eliminating the need for complex schedule management.

Disadvantages : The protocol's complexity in managing dynamic parameter adjustments can increase implementation overhead. Prioritizing high-traffic emergency nodes may lead to fairness matters, causing delays or reduced access for normal nodes

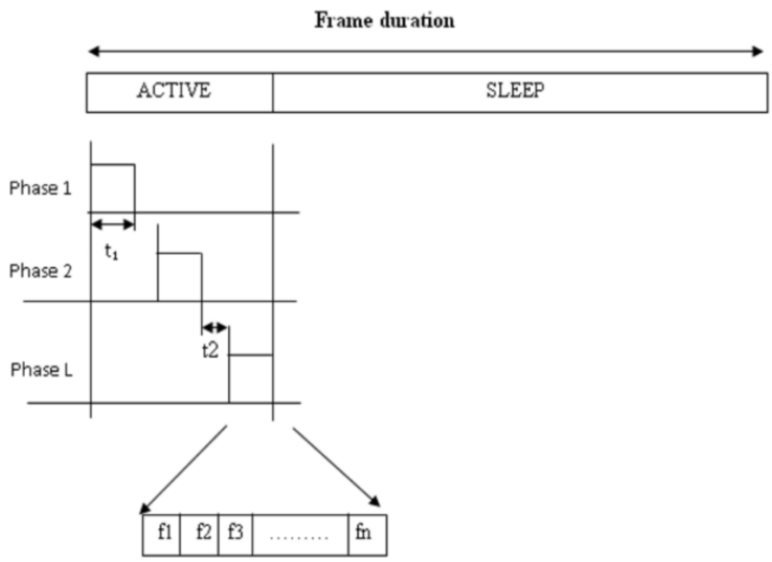

Figure 3.14: Structure of one frame in AD-MAC.

3.3.4.8 FL-CLOM

The Fuzzy Logic-based Cross-Layered Optimization Model (FL-CLOM) protocol is designed to enhance MAC in WSNs. Its primary goal is to optimize network performance by managing medium access and addressing common matters such as congestion, energy consumption, and collision avoidance. FL-CLOM is developed by including the signal-to-noise ratio of the wireless channels in the Transmission Control Protocol (TCP) approach, bridging the transmission layer and MAC layer. A fuzzy logic system is created by integrating fuzzy control with congestion control to dynamically manage the queue size in crowded nodes and minimize the effects of external uncertainties [64].

Advantages : FL-CLOM effectively reduces the rate of collisions in the network and is designed to handle large-scale networks efficiently, maintaining performance even as the number of nodes increases.

Disadvantages : Implementing FL-CLOM may require more complex algorithms and processing power. The initial setup and configuration of the protocol may be more time-consuming compared to simpler MAC protocols.

3.3.4.9 The IEEE 802.15.6 MAC protocol for Wireless Body Area Networks (WBANs)

The IEEE 802.15.6 MAC protocol for Wireless Body Area Networks (WBANs) can be classified primarily as a Hybrid Protocol. This classification is based on its ability to support multiple access methods, including :

1. **CSMA/CA :** This is a contention-based approach, where nodes listen to the channel before transmitting to avoid collisions.

2. **TDMA :** This is a scheduled-based approach, where time slots are allocated to nodes to avoid collisions and ensure timely delivery of data.

3. **Poll-based Access :** This method involves a central coordinator polling nodes to grant them permission to transmit, which helps in managing the network traffic effectively.

By combining these different access methods, the IEEE 802.15.6 MAC protocol can adapt to various traffic patterns and application requirements in WBANs, thereby improving efficiency, reducing latency, and ensuring reliable communication [65].

3.3.4.10 QoS-MAC

The Quality of Service (QoS) Enhanced Medium Access Control (MAC) protocol is designed to address QoS matters in Wireless Sensor Networks (WSNs). This protocol aims to optimize network performance by managing contention and prioritizing mission-important data, thus enhancing overall dependability and reducing latency.

Advantages : The QoS-MAC protocol significantly enhances the quality of service for mission-dangerous traffic. It minimizes delays in packet transmission, especially for high-priority packets. By prioritizing high-priority packets and managing contention effectively, it reduces congestion in the network.

Disadvantages : The implementation of a QoS-MAC protocol is more complex compared to traditional MAC protocols. The added mechanisms for priority management and contention reduction may consume more network resources [66].

3.3.4.11 QoS-MAC

The APCRP (Adaptive Power Control Routing Protocol) is designed for WSNs to enhance energy efficiency, reliability, and network longevity. It achieves this through dynamic route setting and medium-access arbitration. The protocol is implemented and tested using the NS-2.

Advantages : APCRP significantly reduces energy consumption by minimizing the number of route request packets and incorporating energy-aware management techniques. This leads to prolonged battery life for sensor nodes. It decreases end-to-end delays, improving the overall responsiveness of the network.

Disadvantages : Implementing APCRP requires a detailed understanding of the network conditions and careful tuning of parameters, which can be complex and time-consuming. While it reduces the number of route request packets, the protocol might still introduce overhead in managing and adjusting power levels dynamically.

3.4 Discussion : gaps and limitations

Nowadays,MAC protocols have been proposed for due to different problems for WSNs at the MAC layer levels. Each protocol was built for a specific reason to satisfy users,and there are a variety of reasons, such as [5] :

1. **Application Dependency :** Many MAC protocols are designed to meet the needs of a specific target position. That poses a problem as no single network protocol can cater to all WSNs, although some may be applicable to several but not all of them.

2. **Lack of Standardization in Lower Layers :** The formation of hardware standards for the sensor interface and physical layer is a quite challenging matter because there is no valid standard or it is the one that is unsuitable for the purpose.

3. **Diversity of MAC Protocols :** Representative types of MAC protocols like TDMA, synchronous, asynchronous, and some other wireless communication tech-

nologies that are in fierce competition at the moment all opened up new research hot topics.

4. **Trade-offs :** Among the common matters in MAC protocols are energy consumption, throughput, and delay.

5. **IoT and Standard Protocols :** 802.15.4 IEEE and IPv6 protocols that are used for processing the data, and the absence of implementation, hardware availability, and security matters are a few of the problems that needed to be looked deeply at.

6. **Research and Future Improvements :** many research groups are working hard in the everlasting search for more effective treatments, and they are also developing more types of treatments. IEEE 802.15.4e is a promising development that still needs to be corrected.

3.5 Conclusion

In conclusion, this chapter provides a comprehensive overview of protocols based on Medium Access Control (MAC) in Wireless Sensor Networks (WSNs). It identifies a classification system for MAC protocols based on prioritization, serving as a foundation for organized comprehension and evaluation.

The literature review focus on the current state of research, identifying gaps and limitations in existing literature and emphasizing the importance of considering traffic properties and application requirements during protocol design. Further research is needed to address these limitations and gaps, presenting an opportunity for advancement in this field.

Chapter 4

Contribution

4.1 Introduction

A critical challenge in existing MAC protocols for beaconing communications is managing simultaneous access attempts. In this chapter, we focus on our contribution. We present our new MAC protocol, which is a combination of two protocols. Slotted ALOHA (S-ALOHA) and CSMA, our main aim is to optimize channel access efficiency and reduce collisions.

The results of our simulation conducted using the NS2 simulator which show the good performance of our solution.

The rest of this chapter is organized as follows : We will present our contribution through the development of our different phases. Then, we will evaluate and discuss the performance of the proposed approach.

4.2 Proposed Protocol : The Dynamic Slotted-CSMA protocol

4.2.1 Problematic

As seen in figure 4.1, the largest issue with the CSMA-like protocol is the so-called "start-of-interval contention," which occurs when many contender nodes begin transmission simultaneously.

In order to force the participating nodes to conduct CSMA collision avoidance, the medium must be declared busy during the guard interval prior to the contention period, as per the IEEE 802.15.4 standard solution to the start-of-interval contention problem. On the other hand, IEEE 802.15.4 requires tiny contention window (CW) sizes. As more nodes enter the communication range, the collision probability for beacons may increase since broadcast is not subject to the binary exponential backoff of the window.

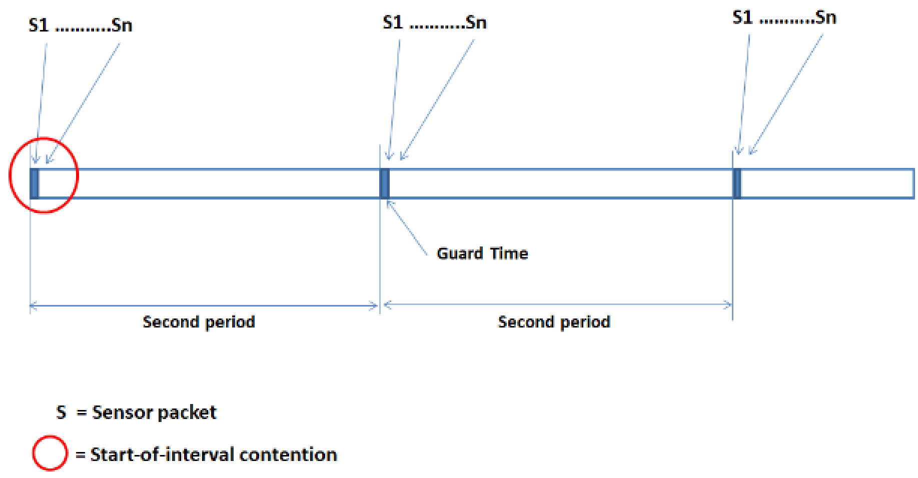

Figure 4.1: The start-of-interval contention problem.

4.2.2 Protocol Description

This section proposes a novel scalable random-access MAC for sensor networks with the objective of preventing the start-of-interval contention problem that occurs at the beginning of each transmission round in the channel (CH). It aims to provide efficient one-hop broadcast access on the CH and attempts to minimize the risk of direct collision problems.

The proposal is called DS-CSMA MAC (Dynamic Slotted CSMA), which tries to combine the advantages and simplicity of the two MAC mechanisms : CSMA and Slotted-ALOHA. It can be seamlessly integrated on top of the IEEE 802.15.4 standard.

Its main idea is to spread the messages of the contending sensor over the CH interval. Therefore, the CH period is virtually slotted in the same way as the S-ALOHA method, where the virtual slots represent the possible Start of Transmission Times (STT) of the sensor messages.The message-spreading process involves randomly assigning a STT from the CH to each sensor message.

Hence, with this mechanism, DS-CSMA MAC aims to ensure a more efficient use of the limited bandwidth available. The DS-CSMA MAC protocol consists of two parts :

1. spreading the sensor messages at the beginning of each transmission round in the CH.

2. medium access : when the STT is reached, a sensor unit has a chance to access the CH and attempts to transmit using the conventional CSMA/CA.

4.2.3 System model

The system under consideration consists of a group of sensor nodes that collect physical information, process it, and transmit it wirelessly to a central node called BS, or sink node, within its one-hop of each other, which sends the data to the final user.

All the sensor nodes wait for the beacon message from the sink node to start the transmission of the collected data at the same time, as shown in figure 4.2.

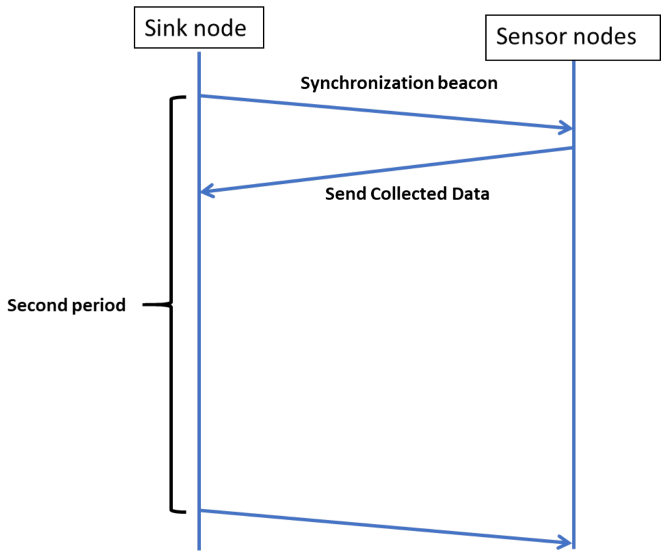

Figure 4.2: Transmission synchronization between the sink nodes and the sensor nodes.

The communication links are assumed to be symmetric, and each sensor unit in the network has the same communications range, which is fixed to a specified value. The carrier sensing range is assumed to be the same as the communications range. The system uses the MAC protocol as defined in IEEE 802.15.4 and operates on one CH, which is used for the transmission of beacon and sensor messages. All the sensors transmit packets of the same size, and they are always transmitted at the beginning of each virtual second period of the CH. They start at the same instant when they receive a beacon message from the sink nodes. So that the time synchronization at the MAC layer is ensured by the sink node.

The CH interval is partitioned into a variable number of virtual slots, whose borders and sizes are calculated at the beginning of each second period according to the sensor packet size. Not like the TDMA method, which uses a constant number of time slots with a fixed size.

For that, the protocol defines the virtual slot (Vslot), which consists of a guard time T_(Guard) a guard interval that accounts for the propagation delay and timing inaccuracy, an AIFS period, the minimum Contention Window (CWmin) interval, and the packet transmission time (Tpacket). Note that the CWmin is used to ensure competition between the nodes having selected the same Vslot when they arrive at the MAC layer. However, with S-ALOHA, the Vslot consists of only T_(Guard) and Tpacket. (see Figure 4.3). The duration of the Vslot value, used by DS-CSMA MAC, can be adjusted according to the CW value and the chosen node packet size as follows :

$$V_{\text{slot}} = T_{\text{Guard}} + T_{\text{AIFS}} + T_{\text{CW}} + T_{\text{packet}}$$

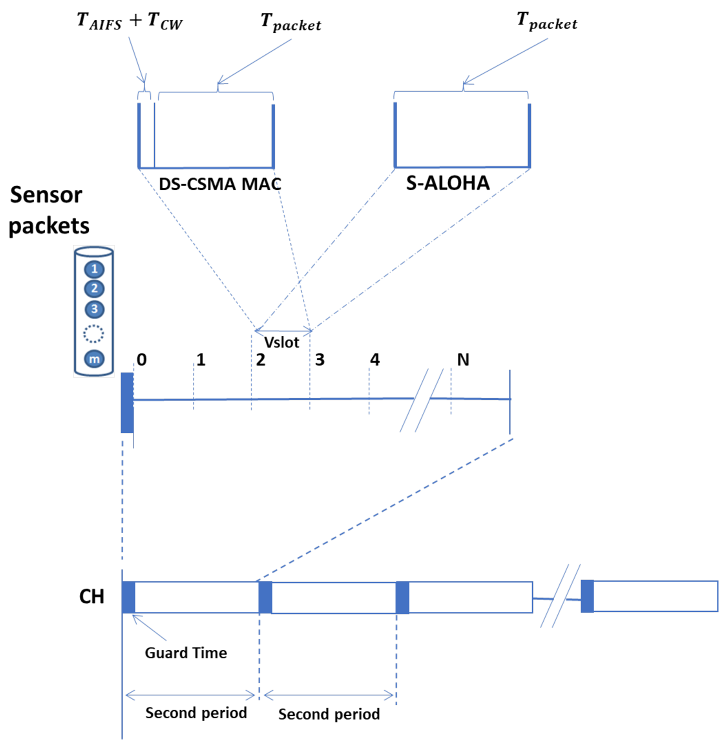

Figure 4.3: Second period, guard interval, CH interval and Vslot interval.

4.2.4 Randomized Sensor Packet Distribution and Backoff Adjustment in DS-CSMA MAC

The proposed idea consists of randomly spreading the sensor packets, based on the S-ALOHA principle, throughout the entire CH time interval (N) ; the main goal is to prevent simultaneous CH access attempts. DS-CSMA MAC adjusts the Backoff according to the T (CWmin) within a one-hop range. At the beginning of each CH interval, each sensor unit randomly assigns the STT in range [0,N] (see Figure 4.4). At the level of the application layer, the arrived sensor packets are spread randomly over the entire CH time interval (N) before being passed on to the MAC layer (see Figure 4.5 and Figure 4.4 (a)(b)). The

STT allocation and the waiting duration before the transmission time (Waiting Time) are defined as follows :

$$\forall Sp \in \text{sensors packets}, \exists \text{STT} \in \text{STT\_CH}: \quad \text{STT} = \text{Random}(0, \text{N})$$
$$\text{and} \quad \text{WaitingTime}(Sp) = \text{STT} \times \text{Vslot}.$$

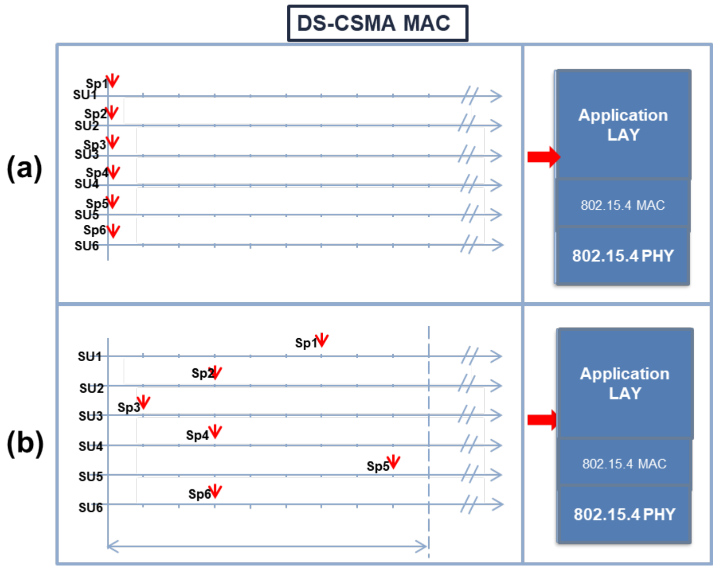

Figure 4.4: DS-CSMA functioning : (a) sensors packets simultaneously arriving to the Application layer ; (b) sensors packets being spread .

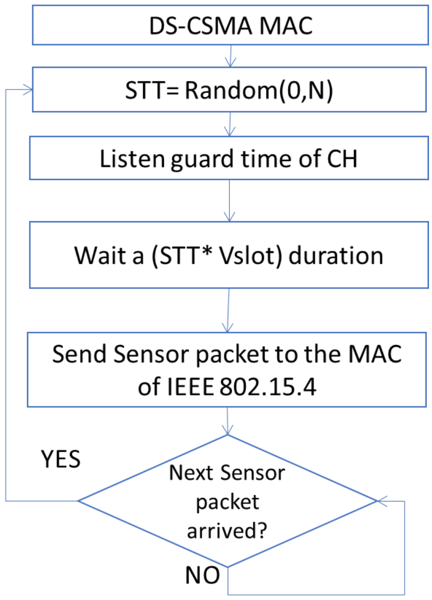

Figure 4.5: The DS-CSMA method for beaconing : the IEEE 802.15.4 procedure.

4.2.5 Medium access using IEEE 802.15.4's CSMA/CA

When it is time for a sensor unit to access the CH and attempt to transmit, the sensor packet is passed to the MAC layer (i.e. IEEE 802.15.4). It may happen that several sensor packets fall within the same STT, meaning that they will compete for CH access. Before transmitting the sensor packet, each sensor unit invokes the back-off procedure using the CWmin to reduce the collision probability between them. The back-off counter is decremented only if the channel has been idle for one physical slot ; otherwise, the counter is frozen until the end of the current transmission. When the counter reaches zero, the sensor unit broadcasts its packets (see Figure 4.6). If there are no contenders for the selected STT, the sensor unit sends successfully without any contention ; otherwise, it will face a risk of collision (see Figure 4.7).

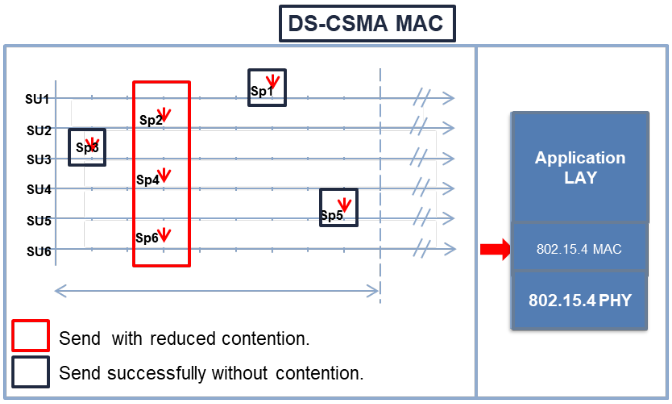

Figure 4.6: DS-CSMA functioning : sensors packets arriving to the Application Layer and being transmitted using a CSMA method.

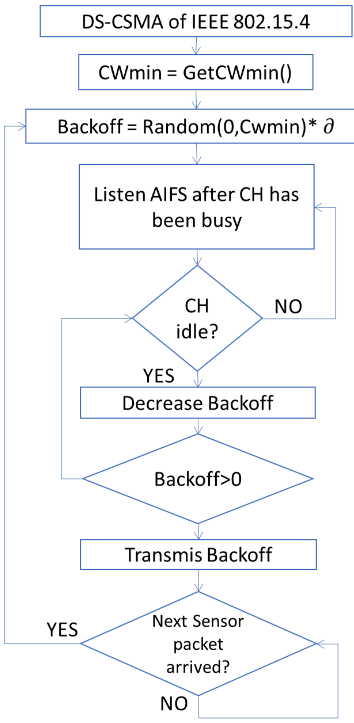

Figure 4.7: The DS-CSMA method for beaconing : the CSMA/CA procedure of IEEE 802.15.4

4.2.6 Algorithm of the Protocol

The entire proposed scheme is presented in detail through the following algorithms : Algorithm.1 and Algorithm.2.

Algorithm 1 DS-CSMA Protocol

Initialization : Start the DS-CSMA process.
while next sensor packet arrived **do**
    Set STT (Start Transmission Time) : STT = Random$(0, N)$
    Listen for the guard time of the CH
    Wait for a duration : STT $\times$ Vslot
    Send the sensor packet to the MAC layer of IEEE 802.15.4
end while

Algorithm 2 DS-CSMA of IEEE 802.15.4

Initialization : Start the DS-CSMA process.
while next sensor packet arrived **do**
    $CW_{\min}$ = GetCWmin()
    Backoff = Random$(0, CW_{\min}) \times \delta$
    Listen AIFS (Arbitrary Inter-Frame Space) after CH has been busy
    if CH is idle **then**
        Decrease Backoff
        if Backoff > 0 **then**
            Transmit Backoff
        end if
    end if
end while

4.3 Simulation study

This section provides an overview of the simulation aspect of the study. It covers the parameters considered during the simulation process.

4.3.1 The simulated protocols

This section presents the MAC protocols to be compared with the DS-CSMA MAC, which is considered a combination of the advantages of the two MAC mechanisms, S-ALOHA and CSMA. The random sensor packet is spread over space using S-ALOHA, and the random back-off is done before sensor packet transmission using CSMA. In order to show the efficiency of combining these two advantages against different types of collisions, it is important to compare DS-CSMA MAC with the original version of the two protocols. Note that with CSMA, the CW used is the same as used in the 802.15.4 standard.

On the other hand, the S-ALOHA use the immediate transmission and without a backoff mechanism. With the S-ALOHA, the slots are randomly and uniformly chosen over the same CH. The slot is called a singleton if it contains only one packet, but if it contains more than one packet, a collision will happen because of the immediate transmission and without the backoff mechanism.

The three MAC protocols under consideration are summarized in Table 4.1.

Tableau 4.1: The simulated protocols.

Protocol	**Abbreviation**
Dynamic Slotted Carrier Sense Multiple Access MAC	DS-CSMA
Slotted ALOHA	S-ALOHA
Carrier Sense Multiple Access	CSMA

4.3.2 Simulation Parameters

To evaluate the performance of the DS-CSMA MAC protocol in comparison with other MAC protocols in broadcasting periodic messages, computer simulations are conducted using the network simulator NS-2. All contender protocols operate over the physical layer of the IEEE 802.15.4 standard. Unlike systems that employ Orthogonal Frequency-Division Multiplexing (OFDM) in the 2.5 GHz band , IEEE 802.15.4 utilizes a different physical layer suited for low-rate wireless personal area networks (LR-WPANs).

All sensor units generate packets of 300 bytes, including protocol overhead, transmitted at a rate of 3 Mbit/s. Considering the guard time (T Guard), Arbitration Inter-Frame

Space (AIFS) period, and CWmin interval, the duration of a time slot is set to one millisecond. Both the communication range and the carrier sensing range are set to 300 meters under free-space propagation conditions. Table 4.2 summarizes the network parameters.

Tableau 4.2: Network parameters

Parameter	**Value**
AIFS	16 μs
Physical slot ,∂	9 μs
CWmin	6
CWmax	Never used (unicast only)
Data rate	3 Mbps
Time Slot duration	1 ms

This segment includes central sink node and sensor units surround it, allowing for unimpeded communication among them.

Sensor units send packets to a central sink node. Each sensor unit has a fixed communication range, ensuring symmetric communication links. All transmitted packets are periodic broadcast packets. The wireless channel is ideal, with transmission collisions being the sole source of packet errors. Sensor units are uniformly and independently distributed throughout the area.

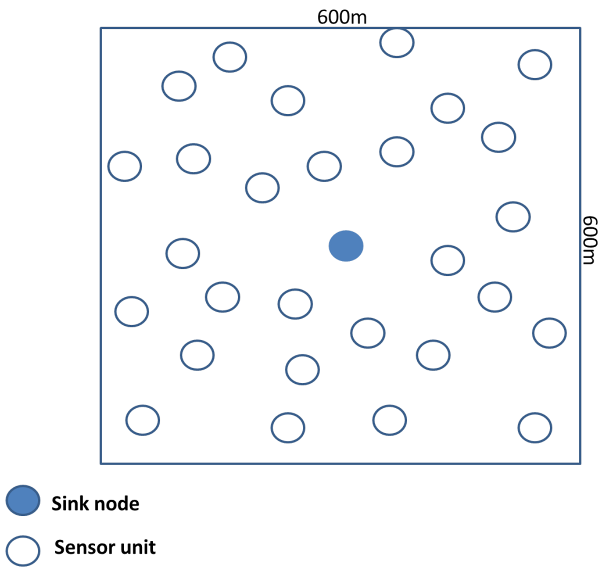

Figure 4.8: Representation of the simulated area.

The scenario is designed to evaluate the efficiency of protocols against merging collisions under low- and medium-density conditions. The simulation results represent the average data from all sensor units, focusing on the impact of various types of collisions, including direct and hiding collisions.

This setup effectively assesses protocol efficiency in a dynamic and realistic simulation environment, addressing the challenges of sensor unit mobility, collision management, and reliable data transmission.

Table 4.3 summarizes the scenario parameters.

Tableau 4.3: The scenario parameters

Parameter	Value
Simulation area	600 x 600
Number of nodes	[20..100]
Frequency (Hz)	10
Transmit Power (Watts)	0.281838
Slot interval	1 ms
Transmission range	300 m
Time of simulation	60 s

4.3.3 Performance metrics

Five different performance metrics have therefore been selected for evaluating the performance of the simulated protocols. These performance measures reflect both specific MAC features as well as the overall C-ITS performance. The following performance metrics are considered :

1. **The Average Medium Collisions :** This metric measures the average number of collisions detected per message sent within the communication range. It is a critical factor in evaluating the efficiency of the MAC protocol in minimizing collisions, which can improve overall network performance and reliability. The average number of collisions :

$$C = N \cdot p_c$$

where N is the number of nodes and p_c is the probability of collision.

2. **The Access Fairness :** Refers to the equitable distribution of channel access opportunities among network nodes. This metric evaluates how well the MAC protocol ensures that all nodes have similar chances of accessing the CH to transmit data. Higher fairness indicates a more balanced and efficient use of the communication medium,Mathematical relation can be represented using fairness index (FI) :

$$F = 1 - \frac{\sum_{i=1}^{N}(x_i - \bar{x})^2}{N \cdot (\bar{x})^2}$$

where x_i is the channel access opportunity for node i, $\bar{x}$ is the average channel access opportunity, and N is the number of nodes.

3. **The Neighbour Awareness :** In the context of wireless networks, this represents the ability of a node to sense and communicate with its neighboring nodes. It evaluates the MAC protocol's effectiveness in detecting and tracking the presence of neighboring nodes, which is essential for bidirectional communication and coordination between nodes. The neighbor awareness can be expressed as :

$$NA = \frac{N_d}{N_a}$$

where N_d is the number of neighbors detected by the node, and N_a is the actual number of neighbors that the node should ideally detect.

4. **The Rx Throughpput :** Throughput measures the rate at which a receiving node successfully receives data packets over a given period. It reflects the efficiency of the MAC protocol and the network in delivering data to the intended recipients. Higher Rx throughput indicates better performance in terms of successful data delivery,Mathematical relation :

$$T_{rx} = \frac{\text{Total number of successfully received data packets}}{\text{Total time}}$$

5. **The Beacon Delivery :** Refers to the fraction of correctly received beacons by a given sensor unit divided by the total number of transmitted beacons from its neighbors. This metric has a relationship with the reception rate of broadcast traffic, which usually depends on the mutual distance between transmitter and receiver where the broadcast traffic sources are uniformly distributed and without re-transmission,we can represent it with mathematical relation :

$$BD = \frac{\text{Number of correctly received beacons}}{\text{Total number of transmitted beacons}}$$

4.4 Simulation Results

4.4.1 The Average Medium Collisions probability

The first metric to be explored is the average medium collision probability of the protocols under consideration interpretation across node densities per Total Highway Capacity (THC), as illustrated in Figure 4.9. As expected, the CSMA of the IEEE 802.15.4

standard indicates a rather high possibility of medium-risk collisions compared to other protocols, and this probability increases with the density of nodes. This goes further in confirming that the medium-access method used by the standard is ineffective in reducing collisions, mainly when the number of nodes in the network is very large. The S-ALOHA protocol demonstrates better performances in comparison with the CSMA, due to the STT spreading technique for the beacon messages that help minimize contention on the CH. The DS-CSMA MAC protocol therefore has a lower rate of medium access and fewer collisions than the CSMA and the S-ALOHA protocols mentioned above. This reduction is a result of the mixture of the medium-access method of operation (CSMA/CA) and the STT spreading technique employed in the S-ALOHA protocol. Moreover, in other words, the collision probability of the DS-CSMA MAC protocol does not significantly increase or decrease with changes in density, ensuring scalability.

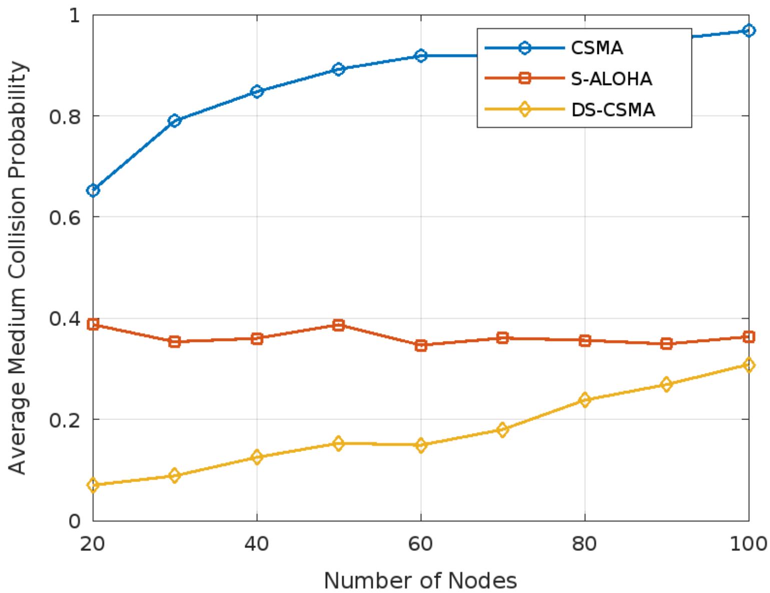

Figure 4.9: The average medium collision probability.

4.4.2 The Access Fairness probability

The performance of the three MAC protocols illustrates the probability of achieving fairness against the number of nodes in the network, as shown in figure 4.10. The fairness issue of access is the worst and fluctuates more frequently in the case of CSMA as compared to the other two protocols. The randomness and lower fairness of access that CSMA often fails to give equal share for all nodes, which becomes demanding when there are many nodes in the network and thus contention is high. This demonstrates poor scale-up on fairness, which decreases and fluctuates with the increase in network size. The probability that access is fair for S-ALOHA is calculated to consistently be higher than for CSMA. It remains relatively stable ; there were no significant increases or decreases over the increase in network size. This can be described as follows : in S-ALOHA, the channel access is divided by the partitioning technique, which provides a higher structure and is more diverse among the nodes than in CSMA. The combination between the two protocols is presented by the protocol DS-CSMA MAC, where this last one proves the biggest chance of access fairness when increasing the number of nodes. The method based on slotting carried out with carrier sensing and back-off does bring important changes to the ways the network nodes can gain access to the channel ; the fairness of access is greatly enhanced, to the degree of guaranteeing that even if the network population increases, all nodes have an equal chance to gain the channel. This confirms that our protocol exhibits the best scalability when it comes to its ability to offer relatively high access fairness at the node level as the number of nodes grows.

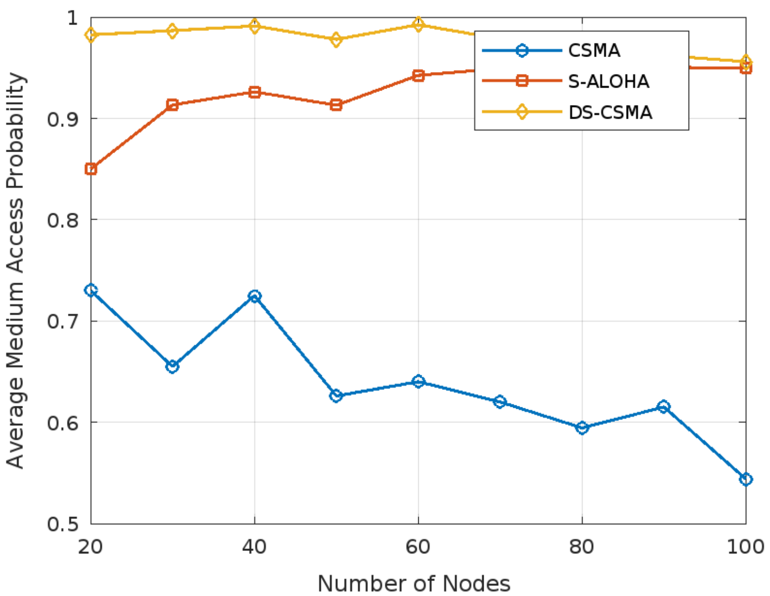

Figure 4.10: The Access Fairness probability.

4.4.3 The Neighbour Awareness

The Neighbor Awareness Probability for both CSMA, S-ALOHA and the proposed protocol DS-CSMA MAC at different node densities per THC is illustrated in Figure 4.11. CSMA has a low initial Neighbour Awareness Probability due to factors such as collision and reduced communication efficiency as more nodes compete for access. This problem is exacerbated by the small contention window sizes and the lack of binary exponential backoff for broadcast messages, resulting in increased collision probability as the number of nodes grows. In contrast, S-ALOHA is comparatively more fastitious, having relatively constant Neighbour Awareness Probability appears with little variation, as shown in the figure below. This better performance compared to CSMA can be attributed to the spreading technique of the STT used for beacon messages, which reduces contention and collisions, hence enabling the nodes to remain aware of their neighbors even as they become denser. As for DS-CSMA MAC, the Neighbour awareness probability is higher than that of the other two protocols over the various node densities analyzed here. High throughput rates are attainable when incorporating the CSMA/CA protocol with the STT spreading technique used in S-ALOHA ; it decreases the collision while at the same time actively ensuring that all the nodes maintain communication. Comparatively, Neighbour Awareness Probability decreases gradually and marginally at very high levels of personalization but is not zero.

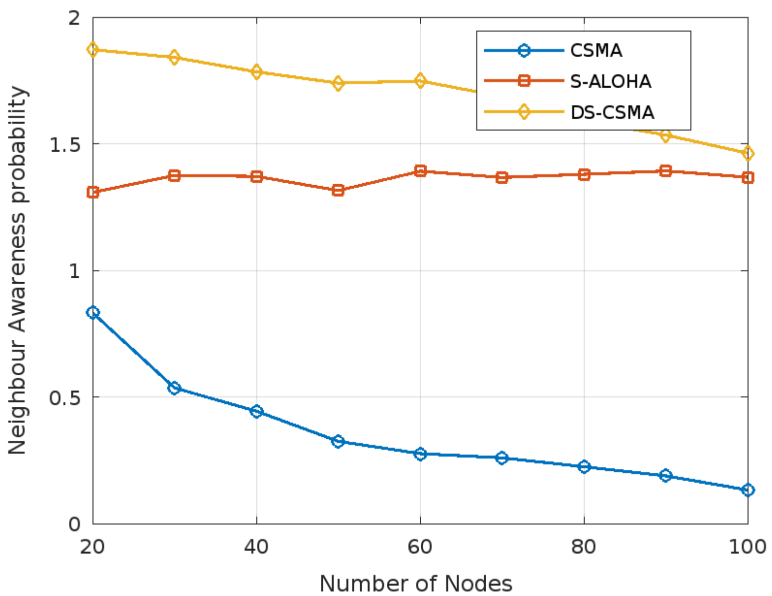

Figure 4.11: The Neighbour Awareness.

4.4.4 The Rx Throughput

As Figure 4.12 demonstrates, the performance of three MAC protocols (CSMA, S-ALOHA, DS-CSMA MAC) by using received throughput (RxThroughput) against the number of nodes in the network. CSMA achieves only a low and constant throughput that does not increase with the number of nodes rises, it is evident that CSMA degrades owing to high collision rates for a large number of nodes and channel contention. Conversely, S-ALOHA has a positive rising tendency in throughput with the increase in the number of nodes, thus showing improved capability of handling node density and good scalability. The best performance is shown by DS-CSMA MAC because it incorporates the best features of the CSMA and the S-ALOHA protocols, such as the back-offs and STT spreading technique, with greater enhancements as the number of nodes increases, implying that there is increased efficiency in handling several nodes in a short time to avoid excessive collisions, carrier sensing, and slotting, thus needing less control than the productivity received.

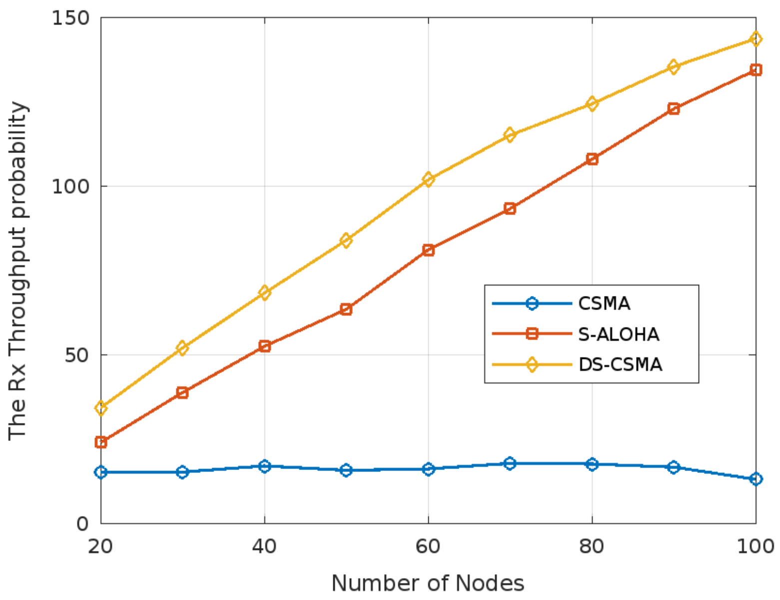

Figure 4.12: The Rx Throughput.

4.4.5 The Beacon Delivery

Figure 4.13 shows the comparative results of three MAC protocols by plotting their average beacon delivery ratio against the number of nodes in the network. For CSMA, the average beacon delivery ratio demonstrates a notable decline with an increasing number of nodes. This has reduced the effect of the protocol at higher density, most probably due to more collisions and contention for the number of available channels, which in the end denotes low scalability with a significant decline in delivery rate when the size of the used network increases. The average beacon delivery ratio of S-ALOHA stays comparatively steady during the simulation while showing a minor raise at the beginning. It is then scaled upward and starts stabilizing as the number of nodes increases. This consistency shows how S-ALOHA has the capability to deliver a more constant signal delivery ratio than in CSMA, which focus on the protocol's effectiveness for dealing with the mounting density of the network and, as a result, supporting the necessary scalability and a reasonably steady delivery ratio. Despite that, DS-CSMA MAC offers the highest beacon delivery ratio on average. As we can see from the figure below, among the three protocols used, there is a slight decrease noticed as the number of nodes rises. Nevertheless, DS-CSMA MAC exhibits probably the most effective way of maintaining high signal throughput as the number of nodes in the network constantly grows and is put as the best option when it comes to situations that require high reliability of escalating network densification.

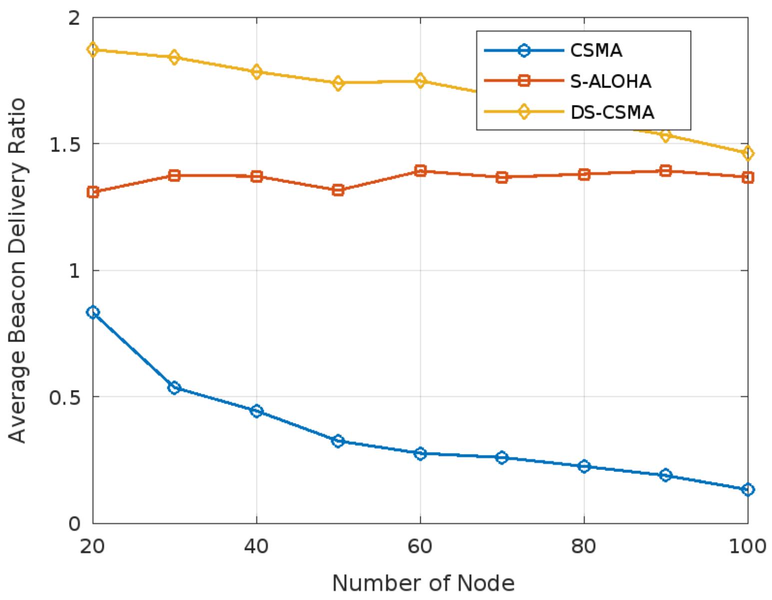

Figure 4.13: The Beacon Delivery.

4.5 Conclusion

In conclusion, this chapter has presented our proposed MAC protocol, DS-CSMA MAC, which integrates the principles of S-ALOHA and CSMA to optimize CH access efficiency and reduce collision probability.

The results of the simulation conducted using Network Simulator (NS2) argue in favor of the efficiency and performance of our routing protocol.

These results have shown that our contribution is effective in achieving significant scalability and consistency.

Overall, the findings of this chapter set the stage for further investigation and refinement.

Chapter 5

General Conclusion

5.1 Summary of our Work

This work is focused to the investigation of MAC in WSN for water management systems, which includes several key steps.

Initially, the first step was to analyze the existing approaches used by the Algerian Water Corporation (ADE) and understand the problems associated with the conventional treatment methods processes in water distribution and consumption management. Further, the introduction of WSN technology was proposed as a method of resolving these challenges that characterized data collection, system monitoring, and efficiency levels. Also, we reviewed a range of existing MAC protocols, categorized them based on their access strategies, and pointed out their advantages and limitations. This review was pivotal when it came to identifying the key features required for designing new protocols needed to address one of the challenges of WSN. After that, in the next step, we did a review of the protocol that was present, defined which protocol was more or less feasible, and figure out their limitations.

Finally, we presented our approach and contribution to the field. Therefore, based on CSMA and S-ALOHA, we established a novel MAC protocol which can help to enhance the overall performance of the network by reducing congestion.

Throughout our research, we conducted extensive simulations using the NS2 simulator to evaluate the performance of our protocol. The results demonstrated the efficiency and effectiveness of our MAC protocol in terms of reduced collisions, improved scalability, and higher throughput.

Our work contributes to the advancement of WSN communication protocols, providing a robust solution for water management systems, and inspires future research in this field.

5.2 Future Perspectives

To expand upon the achievements of this work, it is important to consider several future perspectives for designing novel approaches. The following are the dimensions of future study that point to the possible next steps in the evolution of the topic :

- Integration of security parameters into our MAC protocol (develop robust security protocols to protect against cyber threats and unauthorized access) .
- Conducting performance analysis of our protocol after a real-world implementation.
- Integrating WSNs with broader Internet of Things (IoT) ecosystems can provide more comprehensive and intelligent water management solutions.
- Developing the scalability and robustness of the protocol to manage large-scale networks and maintain performance.

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Appendices

Annexe A

Simulation Script and Tools

A.1 NS2 Installation

To install NS2 in Ubuntu, follow these steps [67] :

1. Install the basic libraries like :

   `$ sudo apt install build-essential autoconf automake libxmu-dev`

2. Install gcc-4.8 and g++-4.8

   Open the file using sudo mode :

   `$ sudo nano /etc/apt/sources.list`

   Include the following line :

   `deb http://in.archive.ubuntu.com/ubuntu bionic main universe`

   `$ sudo apt update`

   `$ sudo apt install gcc-4.8 g++-4.8`

3. Download and extract the NS2 software from :

   Installation of NS2 in Ubuntu 22.04 | NS2 Tutorial 2

4. Extract it to the home folder '/home/user'

   `$ tar zxvf ns-allinone-2.35.tar.gz`

   or right-click over the file and select "Extract here" and choose the home folder.

   `$ sudo apt update`

5. Make the changes in the following files :

- ✓ ns-allinone-2.35/Makefile.in
- ✓ /home/pradeepkumar/ns-allinone-2.35/otcl-1.14/Makefile.in
- ✓ nam-1.15/Makefile.in
- ✓ xgraph-12.2/Makefile.in

Replace '@CC@' with 'gcc-4.8'
Replace '@CPP@' with 'g++-4.8'
Open the file 'ns-2.35/linkstate/ls.h'
Change line 137 from :

```
void eraseAll()  erase(baseMap::begin(), baseMap::end());
```

to :

```
void eraseAll()  this->erase(baseMap::begin(), baseMap::end());
```

6. Open a new terminal and run :

```
$ cd ns-allinone-2.35/
$ ./install
```

7. Set up environment variables : Edit the .bashrc file to include the NS2 path. Open the file using a text editor :

```
$ gedit .bashrc
```

Paste the following lines :

```
export PATH=$PATH:/home/<yourusername>/ns-allinone-2.35/bin:/home
/<yourusername>/ns-allinone-2.35/tcl8.5.10/unix:/home/<yourusername>
/ns-allinone-2.35/tk8.5.10/unix
export LD_LIBRARY_PATH=/home/<yourusername>/ns-allinone-2.35/otcl-1.14:
/home/<yourusername>/ns-allinone-2.35/lib
```

8. Reload your .bashrc by running :

```
$ source .bashrc
```

A.2 Algorithmic Scripts

Our proposed MAC protocol is represented by the class named Newprotocol, Here is the link to our GitHub repository : GitHub Repository, where you can find the principles codes that we use.