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A SURVEY OF MAC PROTOCOLS FOR LINEAR WIRELESS SENSOR NETWORK

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ABSTRACT

A Linear Wireless Sensor Network (LWSN) is a wireless sensor network where all nodes in at least one level of the network hierarchy are in a line. The architecture and protocols proposed for a general WSN may not be suitable for linear applications like monitoring pipelines and railways, and therefore we must present the applications needing Linear WSN and study the specific design requirements for it. This paper illustrates the importance of LWSN through applying various potential applications that use LWSN in order that they may benefit in terms of reduced time and cost of network deployment and maintenance, large scalability, and easy deployment of nodes in the network. The paper begins by presenting a new classification for LWSN in network topology (linear sequential, linear parallel and grid) and in network hierarchy (flat architecture, multi-hop architecture and hierarchical architecture). Then, a detailed explanation for almost all potential applications of LWSN is given. The paper ends with a discussion on different open research areas that need to be studied and argued over by researchers in the future in order to complete our understanding of (and the benefits to be derived from) LWSN in various applications.

Keywords— Linear wireless sensor networks (LWSN), WSN, Potential Applications, Linear Sequential, Linear Parallel and Grid.

INTRODUCTION

In many environmental monitoring wireless sensor network applications, a sink gathers data from battery-operated sensors which are deployed on topologies that are mostly linear and this kind of networks are called “linear wireless sensor networks (LWSNs)” [1]. LWSNs are used in a number of specific application scenarios such as monitoring bridges [2], gas or oil pipelines [3] and roadside or highways (e.g accident detection on highways) [4]. Another interesting application scenario for LWSNs is related to railroad/subway operation and monitoring. Long freight train themselves have a linear structure by nature and sensor modules with external sensors can be deployed near or on the wheels where failures most commonly occur. For example acoustic sensors might be used to detect cracked or flat wheels, while a thermocouple might be used to detect overheated wheel bearings. The sensor modules relay sensor data and alert the base station, which is deployed on the locomotive [5, 6, 7].

A miner monitoring system, deployed in the confined environment of a coal mine can be used to keep track of the situation in the mine and the activities of the miners. It is an example of an ultra-sparse network with linear topology [8, 9]. Underwater pipelines extend for hundreds of kilometers at depths reaching hundreds of meters and are subjected to high pressure. At such depths, it is really difficult to perform maintenance activities. So, LWSNs can be used for monitoring underwater pipelines [10, 11, 12]. In greenhouse agriculture, LWSNs can be very useful to monitor crop's growing environment. After measuring and transmitting crop's environmental parameters to farmers, they can make decisions based on the data to improve yields and quality [13]. Another LWSN application example is the case of a speleologist going deep down into the bowels of the Earth, who can deploy the wireless network in order to maintain a communication channel with the outside world [14]. In [15], a lightweight lap time measurement system based on wireless sensor nodes that are linearly deployed for Alpine skiing is presented. Another application example of LWSNs is Parking Sensor Network (PSN) which is a special form of WSN. It is rapidly attracting attention around the world and is regarded as one of the first implemented urban services in smart cities (*i.e.* "Smart Santander") [16].

Among the numerous applications of sensor networks, monitoring systems for electric cable, boats in a watercourse, smart grids, borders and production line are other examples of linear wireless sensor networks [17, 18, 19, 20].

It is obvious that the number of applications requiring LWSN is continuously increasing. That is why a growing number of researchers are turning to investigating the specifics of these networks and proposing new, more tailored solutions for increasing their efficiency and performance.

This paper aims to provide a systematic overview of the recent developments in the area and discusses some of the most recent and promising MAC protocols specifically developed for LWSN.

The paper is organized as follows. In Section 2 we describe LWSNs with their challenges. In Section 3, we describe the potential benefits of LWSNs. In Section 4, we describe the classification of linear wsn. In Section 5, we describe mac Protocols to resolve these challenges and then we conclude the paper.

1. Challenges in linear wsn

One of the major challenges in LWSNs is to ensure the end-to-end packet delivery relaying on a more limited number of relay nodes than other WSNs. Clearly, nodes closer to the sink end up forwarding or relaying more packets than nodes further away. Over time, this uneven load distribution, known as the "relay burden problem", results in a disproportionate share of energy consumption and leaves the "close-in" nodes with considerably less energy. Therefore the risk of prematurely terminating the network's lifetime is greatly increased. At the same time, these nodes cannot afford long sleep times because they must be alert, in idle listening mode, to carry out their relaying functions[6]. Thus, more intelligent methods for traffic load distribution must be applied in order to ensure and prolong the network lifetime.

Due to the linear topology of the network data delivery is more exposed to failure in LWSNs than in classic WSNs. A single node failure can totally disturb the communication process in the network which is an obvious weakness of LWSNs. Nodes can fail due to battery exhaustion, hardware failures, and natural or intentional damage. This kind of failures may cause drastic problems so innovative recovery solutions need to be considered at the MAC layer since there are no alternative routing possibilities to the sink. Furthermore, consecutive faulty nodes form holes which may cause the LWSN to be divided into multiple disconnected segments and failure of overloaded nodes closer to sink may cause terminating the network's lifetime. Some interesting approaches related to failure recovery in LWSNs have been proposed in the literature so far[7,8].

In LWSNs, it is also difficult to deal with the accumulation of the traffic produced by each node.

Nodes closer to the sink tend to be more congested than the others, channel access becomes more difficult which leads to buffer overflow and packet drop. As a result both packet loss and end-to-end latency is additionally increased[9]. One possible solution can be assigning bigger buffers to the nodes closer to the sink. However this simple approach is not always a viable solution since most WSN nowadays use off-the-shelf components with standard characteristics. Such a solution would require bringing heterogeneity in the network which would increase the implementation cost. Another important issue in LWSNs is energy consumption. Due to the linearity of the network and the traffic congestion created in the nodes close to the sink, there is an unbalanced energy consumption profile in the network. Also, the nodes in the network can experience exposed and hidden terminal problems which induce high latency and frame collisions. Thus, techniques for balancing the energy consumption should be considered while ensuring data traffic is being delivered within an accepted delay margin[10.]

2. **Potential benefits of linear wsn**

There are some potential benefits LWSNs may be able to offer. For example, nodes know their neighbours' position, can schedule packet transmission beforehand and regulate the duty cycle accordingly. This has been used by a number of researchers[11,12]. In most cases nodes are deployed at equal distances which creates advantages positioning and synchronization[6]. Random node deployment along a line or chain provides advantages in formulating clusters, which has been used in some studies to introduce hierarchy in the network in order to regulate the load and the energy consumption. On the other hand, since the topology is already known, additional control overhead for network discovery is minimal. Thus, well known techniques like flooding are not required in LWSN.

As routing solutions are very limited in LWSN, many researchers focus their attention and efforts on the MAC layer to solve the issues described above. Thus, there are some existing MAC protocols especially designed for LWSNs. However, study comparing superiority to each other almost none. In this paper we compare and discuss two representative MAC protocols of LWSNs in terms of energy consumption, delay and throughput.

3. **CLASSIFICATION OF LINEAR WSN**

LWSNs can be divided into categories from two points of view: topological and hierarchical. This will be discussed later but here we define the types of network nodes and their functions. There are three types of nodes in LWSNs:

Sensor Nodes (SNs): These are the most common nodes in the network. Their main function is to sense the data and transmit them to the Forwarding Node. Sensor nodes are the basic constituents of LWSNs; primarily, they are engaged in sensing, computation and communication.

Forwarding Nodes (FNs): Routing, aggregation, data compression and transmitting data are the main functions of these nodes.

Distribution Nodes (DNs): These deliver the received data from the FN to the network control center or base station. Different technologies can be used to transfer data; for instance, cellular technology or satellite

Network Topology

LWSNs can be divided according to their network topology into *linear sequential*, *linear parallel* and *grid* WSNs, as the infrastructure of the potential linear applications could be one of these three types.

Linear Sequential WSNs: Some linear applicat-ions, such as border and pipeline monitoring, require the sensor nodes to be placed a single line. In this topology all the nodes are lined up so that the data are transferred through this single line. This topology has a fewer number of nodes but there is no alternative route when a failure occurs.

Linear Parallel WSNs: Some linear applications, such as railway track monitoring, require the deployment of parallel nodes. This topology deploys the nodes in a linear parallel manner. The nodes can send the data via the other route if a failure occurs. The advantage of this topology is that it allows for alternative paths for data transfer.

Grid LWSNs: In this type, each node is connected to neighbouring nodes along more than two dimensions. Paddy field monitoring systems belong to this type of topology.

Network Hierarchy

As in [4], LWSNs can be categorized into: *flat*, *multi-hop* and *hierarchical* LWSN architectures. Before discussing these categories, it is important to know that each LWSN must belong to one of the topological categories and one of the hierarchical categories. This depends on the nature of the application and its requirements. Figure 1 shows an overview of LWSN classification.

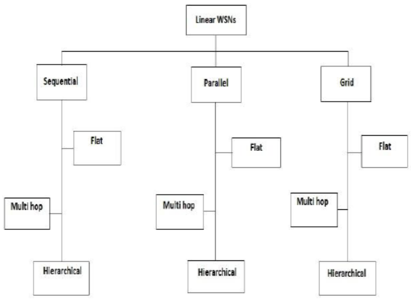

Fig. 1. Overview of LWSN types

Flat LWSN Architecture: Sensor nodes in flat LWSN architectures send their data directly to the base station or control center. This kind of architecture is suitable for very small-scale applications because it is fast in terms of data delivery. However, the limited energy of the sensor nodes can be quickly depleted due to the long-range transmissions. Also, the transmission range of the sensor nodes is relatively small, and therefore they cannot send the data to a base station over a long distance. Figure 2 shows a linear sequential WSN in a pipeline with a flat architecture.

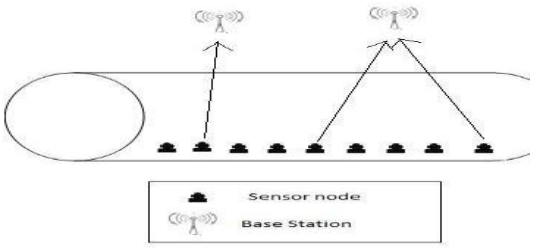

Fig. 2. Linear sequential WSN with flat architecture

Multi-hop LWSN Architecture: Sensor nodes send their data to the base station in multi-hop fashion. Each sensor sends the data to its neighbor, which then sends the data on to the base station. This type is efficient for medium-length LSNs, as it avoids the limitations of flat architecture. However, it takes a long time to reach the base station, especially in large networks, and it is difficult to maintain the network if there is a failure. A parallel LWSN in a railway track with multi-hop architecture is shown in Figure 3.

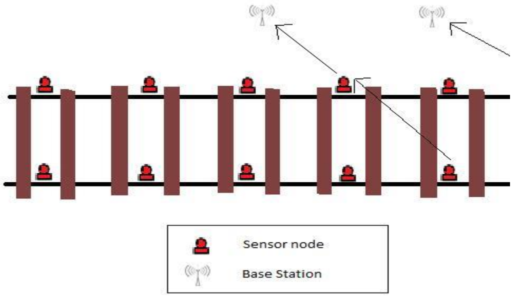

Fig. 3. Parallel LWSN with multi-hop architecture

Hierarchical LWSN: This is where the sensor nodes are grouped in clusters and each cluster is managed by a cluster head. The cluster head receives messages from the cluster members and transmits the aggregated messages to the neighbor cluster head or directly to the base station. This architecture has lower latency than the previous type and the messages are transmitted through fewer hops. Figure 4 shows a grid LWSN in a paddy field with hierarchical architecture.

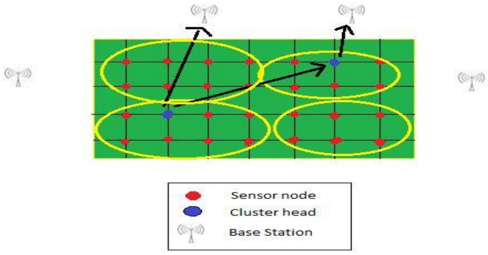

Fig. 4. A grid LWSN with hierarchical architecture

4. MAC PROTOCOL FOR LWSN

In the literature we can find some examples of MAC protocols that are specifically aimed for linear topologies.

In [33], authors propose a hard real-time MAC protocol with realistic assumptions for a random linear network, where sensors are deployed randomly along a line. The goal is to guarantee message delivery before certain deadline. There are four phases (initialization, switching, unprotected and protected mode) of the protocol. The initialization phase's goal is to organize the network nodes into cells so that all nodes of a cell can communicate with all nodes of the two neighboring cells. In this phase, the sink node emits *CC (i)* message, creating cell *i*. All nodes that receive this message emit another *CC* message according to a Timer called *back off* $_{\text{initialization}}$ which is proportional to their distance to the sender. The furthest will emit

First. During this back off time, each node records the number of *CC* messages it has received, the time of reception of the last one and the number of the last created cell. When emitting a *CC* message, a node also starts *timer* $_{last}$. If it expires before receiving any new message, the node knows it is the

Last node of the network, and sends out an *END* message. *END* message informs the sink node the initialization phase has ended. At the end of this phase, each node will know *I* the cell it belongs to, and *R* its position inside the cell. Also, it is assumed that each node knows its absolute position *A*.

After the initialization, run time can start in unprotected mode which offers near optimal speed for message transmission towards the sink (Fig. 6). If a collision occurs in unprotected mode, the network switches to protected mode. This mode guarantees collision-free functioning with bounded transmission times and shown in Fig. 7. It uses the cell based organization created during initialization phase. The overall idea is to reserve 5 cells ahead (*i.e.* towards the sink) of the sending node before sending the alarm message, using signaling messages. Once reserved, a cell cannot generate new alarm message which may cause collision. After reservation, the ALARM message which can be any of length is transmitted in unprotected mode.

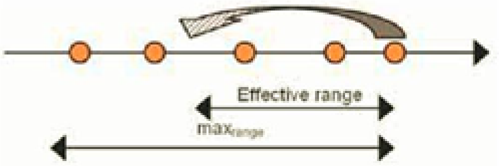

Fig. 5. Unprotected mode

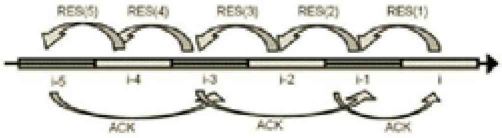

Fig. 6. Protected mode

It is up to the sink to switch back to unprotected mode. Switching back to unprotected mode yields very good transmission times. The sink decides based on the rate of arriving alarms: if there are few, the network is considered not congested and switching back should not lead immediately to collision. Switching is physically done using a jamming message *JAM.* Each node emits this JAM message once when it hears another *JAM* message or detects a collision. Simulations has been used to quantify the speed of the protocol and results has shown that a hybrid approach (using protected & unprotected mode) provides good performance and can be very attractive for real-time linear networks.

DiS-MAC [34] is a Directional Scheduled MAC protocol which guarantees collision-free communication between synchronized sensor nodes arranged in a linear topology. It uses the advantages of directional antennas, increased spatial reuse, higher gains, longer ranges between communicating nodes and eliminates the interference and collisions by pointing the radio beam in the desired direction. This protocol has been implemented for highway monitoring. In DiS-MAC, each node is equipped with one transceiver and a directional antenna with a single beam of high gain in a particular direction, and a lower gain back lobe in the opposite direction.

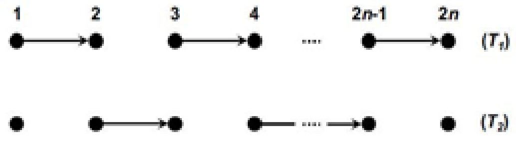

Fig. 7. DiS-MAC topology and operation

Channel access in DiS-MAC is divided in two phases (Phase I and Phase II). Each phase has duration of T_1 and T_2. (optionally $T_1 = T_2 = T$). When the system is in Phase I, only the nodes in positions 2n-1 on the chain are allowed to transmit for a time interval T_1 where n corresponds to each node's position on the chain as shown in Fig. 8. Similarly, during Phase II, the rest of the nodes (*i.e.* the ones located at 2n points) on the chain can access the channel and transmit their packets. During a *scheduling cycle* that lasts for *2T* all nodes have been in two possible states, transmitting or receiving and packet transmission occur simultaneously.

Compared to contention based protocols DiS-MAC does not use RTS/CTS packets and the use of directional antennas provides a solution to the collisions and hidden terminal problems and also avoids the control packet overhead. In addition, per hop latency is minimized as there is no back off mechanism and the latency can be approximated by *2T*. However, the main focus of the paper is throughput rather than the delay. Simulations have been done under three main scenarios: only the first node acting as source, all nodes generating packets and all nodes generating packets and these packets are forwarded to a final destination defined by the probability *q*. Results show that the protocol provides stable and reliable links between nodes. However, larger payloads results in more errors and degradation of the system performance. The authors suggest that in case the transmission of large packet is required, the incorporation of channel coding and data fragmentation techniques should be considered with Dis-MAC.

LC-MAC (Long-chain MAC) [18] is a duty cycle medium access control protocol that exploits a mechanism for relay nodes booking in advance and transmitting in a burst manner in order to reduce the end-to-end delivery delay in a long-chain sensor network scenario without sacrificing energy efficiency. There are three steps involved. The first step is the location detection and it is like an initialization phase. At the beginning of initialization relay nodes detect neighboring relay nodes. The relay node which only has one neighboring relay node will set itself as an end point of the long-chain. This end node is noted as R_n and is shown in Fig. 9. Then, R_n will send a Location Detect Package (LDP) including its address to its neighboring relay node. The neighboring relay node that gets the LDP will add its address into this package and send it to another neighboring relay node. The LDP will be relayed and finally reach the sink. The sink sends the LDP with address table back along the route it came (Fig. 9). As a result, relay nodes can get their location information.

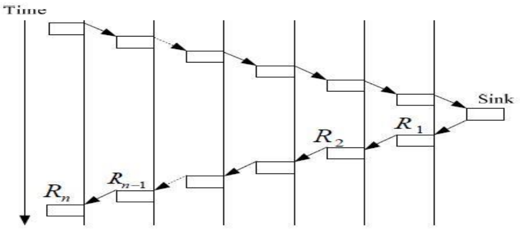

Fig. 8. Distance detection mechanism of LC-MAC

During the second step super SYNC message passing is Done. Every relay node will create a Staggered Wakeup Schedule (SWS) for relaying super synchronization (SSYNC) message. . The SWS for a relay node is calculated according to the node's location. For a relay action, it doesn't include RTS (ready to send) or CTS (clear to send), because every relay node follows the SWS to transmit SSYNC, so collision can be avoided. SSYNC relay action is shown in Fig. 10.

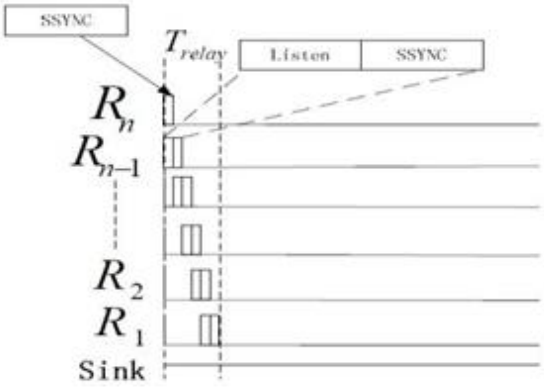

Fig. 9. SSYNC relay action of LC-MAC

The SSYNC is composed of a transmission information part and a registration part. The transmission information part includes a sleep schedule and address information. The registration part is divided into n fractions for n relay nodes. Each fraction has a space p bits to register the number of packets which are going to be send. Once the endpoint is confirmed, the length of SSYNC is fixed. Any relay node getting SSYNC will update it. After the second step, every relay node gets the information about the number of data packets belonging to each relay node. Then, every relay node will calculate the time point to wake up and relay the data packets. It is also a staggered wake up. At the last step the burst transmission occurs for the network. The SSYNC frame structure and an example of burst transmission is shown in Fig. 11. The authors evaluate the performance of LC-MAC through simulation, comparing LC-MAC with S-MAC and S-MAC with adaptive listen mode [35]. Results show that LC-MAC performs much better than S-MAC with more than 99% decrease in latency, a small amount decrease in energy consumption and a better throughput in heavier traffic for long-chain scenario.

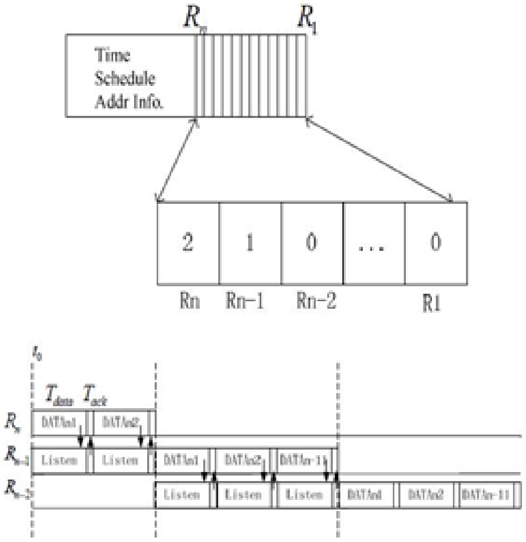

Fig. 10. SSYNC framework and burst transmission with staggered wakeup

In [5], authors apply the RTS/CTS (Request To Send/Clear To Send) mechanism of IEEE 802.11 [37] to the unslotted CSMA/CA algorithm of IEEE 802.15.4 [38], in a linear sensor network. The CSMA/CA procedure has shown to be an effective approach to increase throughput in shared medium environments. Also, the RTS/CTS mechanism is used to reduce the effects of collisions caused by the hidden terminal. The authors point out the benefits of combining these two mechanisms for reducing packet drops. They also argue that the combination helps reduce collisions as well.

The algorithm of the protocol can be summarized as follows. When a node has a data frame to send, it first attempts to send a RTS with unslotted CSMA/CA. If the channel is detected idle in at most five attempts, the pending frame can be sent and the receiver replies by sending a CTS without backoff. Otherwise the current frame is dropped in order to fight against the medium overload. When the sender receives the CTS, it sends the data frame directly.

Finally, the receiver sends an acknowledgement (ACK) as soon as the data frame transmission ends. RTSs and CTSs contain the maximum duration of the whole exchange. When a RTS is transmitted, a timer is started at the sending entity with a duration of $t_{RTS} + 2t_{TA} + t_{CTS} + t_{DATA}$, where t_{RTS}, t_{CTS} and t_{DATA} are the time to transmit a RTS frame, a CTS frame and the data frame respectively and t_{TA} is the turn-around time. The length of the data frame is included in the fields of RTS and CTS frames. When a node receives a RTS or CTS concerning another node, a timer is also started with duration depending on the length of the pending frame. Unslotted CSMA/CA stops decrementing its back off counter. Once the timer has expired, unslotted CSMA/CA continues reducing the original back off. Also, there is a tradeoff between the duration required to send RTS/CTS and the length of the data frame. For small data frames, the benefit of RTS/CTS mechanism is reduced.

The authors propose a *leaky shift register* model which is shown in Fig. 12. Packets flow from left to the right, hence the name *shift register.* With this model, some frames can be dropped or lost, hence the name *leaky register.*

In this model, there are three reasons for a node to drop or lose packets: Medium overload, FIFO overload and Retransmission credit exceeded.

(ACK), the main one being traffic overload. The authors focus on the evaluation of the leaky shift register. They study the relationship between the register parameters (the local traffic load, the number of nodes and the size of the node queue) and the leaks of the register with and without the RTS/CTS mechanism. In the leaky shift register, forwarded packets become increasingly important as they get closer to the sink. Simulation results show that the number of dropped packets decreases significantly with RTS/CTS, as well as the load of the queues, at the cost of a slight increase in delay.

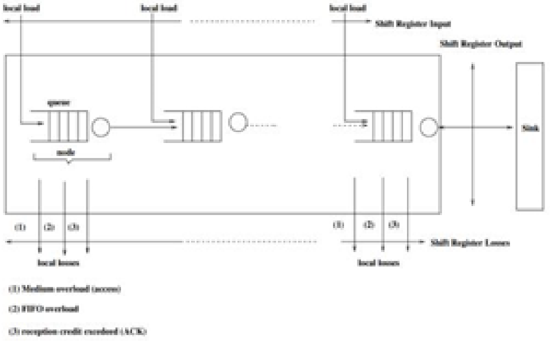

Fig. 11. The leaky shift register model

CMAC-T [13] is a chain-type medium access control protocol based on tokens and is designed and implemented for monitoring crop's growing environment. The protocol is combined with access on demand and stationary distribution of time slots. It uses two main types of frames, beacon frame and data frame. Beacon frames are responsible for the synchronization between adjacent nodes and assigning channel permission. Frame length is stable. It includes two bytes. The first one stores token information and the other one stores the number of nodes in the network. Token is different in different periods. Each node, except uploading its own data, has to transmit other node's data. So the length of data frame is changeable for different nodes. Data frame also includes the node's ID and alarm information. Alarm information is one bit indicating that the node has low power level.

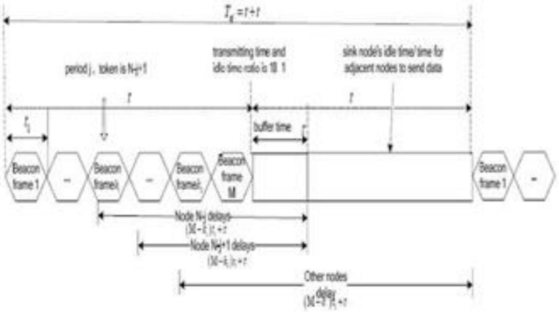

Fig.12. Synchronization and communication process of CMAC-T.

In CMAC-T, synchronization is done by using beacon frames. The sink node periodically sends a certain number of beacon frames. After waking up from sleeping state, nodes in the network randomly receive a beacon frame containing a time slice and token information, which can determine whether nodes get the communication authority. If the get it, they finish synchronization and later complete data transmission between adjacent nodes. Otherwise, they will continue to sleep. In this way, the network not only avoids data collision in data transmission, but also reduces the power consumption (Fig.13). The authors state that CMAC-T has been applied in A greenhouse and has satisfied the requirements of high reliability and low power consumption. MFT-MAC (Multi frame transmission MAC) [39] is a contention-based duty cycled MAC protocol using a synchronized approach. It uses a control frame called PION that considers the number of DATA frames to be transmitted to the next node in order to improve the energy efficiency and reduce the end-to-end delay. MFT-MAC forwards multiple data frames over the multi-hops in a single duty cycle in order to reduce energy consumption without sacrificing the end-to-end delay. The protocol is well suited for data collection applications in which sensor nodes have to reach the sink node through multi-hops in a chain topology. There are three periods in a single cycle: SYNC, DATA and SLEEP. Nodes synchronize their clocks with the required precision in the SYNC period. In the DATA period, the source node contends with its neighbors and setups a forwarding path using the control frame for sending the data to the sink node in the SLEEP period. SLEEP period is the actual data transmission period but only the next hop node wake up according to the schedule created in DATA period and the other nodes sleep in this period. The control frame PION is similar to the RTS/CTS mechanism and solves the hidden terminal problem. PION includes all fields of RTS/CTS and the final destination address, the hop count and the number of multi frames. In the SLEEP period the nodes wake up at some specific time in order to receive the multi frames and then go back to sleep after transmitting data frames of its own plus received from the previous node. The number of DATA frames transmitted in the SLEEP period is determined using the number of PIONs transmitted in the DATA period. If the number of nodes in the chain is greater than the number of PIONs, the transmission should be continued in the next cycle. The operation of MFT-MAC is shown in Fig. 14. Authors compared the MFT-MAC with DW-MAC [40] and R-MAC [41] protocols which use an adaptive duty cycle. Results show that MFT-MAC is superior to the DW-MAC and R-MAC in regard to average power consumption, average end-to-end delay and throughput.AC-MAC/DPM (Adaptive Coordinated MAC protocol based on Dynamic Power Management) [42] focuses on reducing the number of transceiver state switches. It guarantees low delay, high throughput and reduced energy consumption when the traffic load is high. In order to reduce the energy consumption due to transceiver state switching between idle and sleep, AC-MAC/DPM uses Dynamic Power Management [43] mechanism. The basic principle of the protocol is to control the value of T_i which is the duration between transition to sleep state and active state. The protocol calculates a value called R_i which is the number of new duty cycles according to sensor’ traffic load. The number of packets queued at the MAC layer is an indication of the traffic load. A node announces the value of R_i through the RTS/CTS packets. On receiving RTS/CTS packets, all nodes either within one-hop of the transmitter or the receiver, may follow the same new duty cycle during one basic cycle time. One node accepts only one R_i value within one basic cycle time. The algorithm for deciding the number of chances of communications within one basic duty cycle is shown in Fig. 15. The authors compare the AC-MAC/DPM with the S-MAC protocol. They the end-to-end delay of packets in a multi-hop linear topology. The results show that when the traffic load is high AC-MAC/DPM can be more efficient than S-MAC in terms of delay and energy.

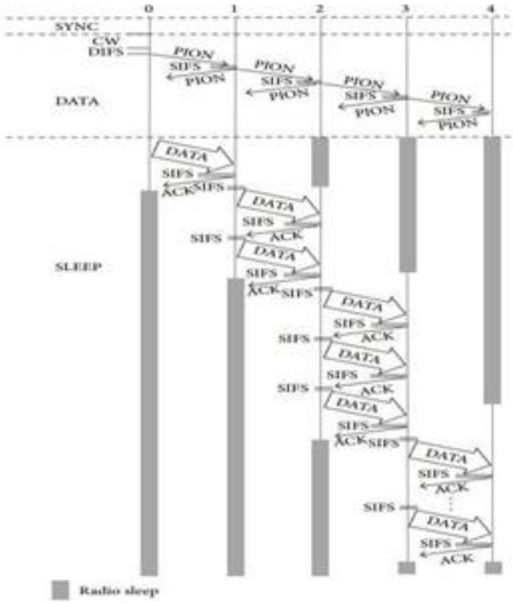

Fig. 14. The MFT-MAC operation

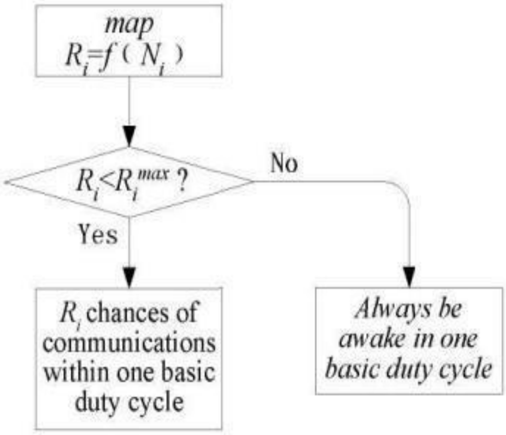

Fig.15. Algorithm for determining the chances of communication within one basic duty cycle.

WiWi [14] is a contention-free MAC protocol based on synchronous multi-hop transmission along a chain of independent nodes. Devices are displaced in order to build up a linear (or curvilinear) strip. WiWi recalls some DiS-MAC features; in particular both protocols avoid interferences between simultaneous transmissions by alternating transmissions between adjacent nodes. However, WiWi does not require directional antennas; it provides bidirectional communication over a single RF channel. The communication between WiWi nodes is synchronous, based on fixed size packets and follows a staggered pattern. The downstream data flow proceeds downwards from the head of the chain to the tail. Every node resynchronizes its clock upon the start of the incoming down-stream packets. Once a node is synchronized with the downstream flow, its activity pattern is receive-transmit-idle-transmit-receive-idle (R-T-I-T-R-I) regardless its position in the chain. The upstream flow follows the same principle of passing messages along the chain, but between the reception of a packet and its forwarding, the node waits 4 time slots in order not to collide with the downstream one and it is shown in Fig. 16. Moreover, WiWi nodes require no explicit addressing because within the range of transmission there is only one receiving node (*i.e* the next hop for the packet). The authors argue that WiWi provides deterministic and predictable latency and throughput in both directions. However, in this protocol power consumption is not considered.

5. **Conclusions**

In this paper we have addressed a specific group of WSN, the linear WSN. We have summarized their characteristics and challenges and provided an in-depth overview of recently proposed MAC protocols that aim to solve these specific challenges.

6. **References**

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