Redundant Communication Avoidance for Event-Driven Wireless Sensor Network

Hung-Cuong LE †, Hervé GUYENNET † and Noureddine ZERHOUNI ††,

† Université de Franche Comté, Besancon, France
†† Laboratoire d'Automatique de Besançon, France

Summary
In this paper, we introduce a new medium access control (MAC) protocol for event-driven wireless sensor networks (WSN). Generally, there are three models of WSN: continuous, on-demand and event-driven. They have different characteristics and each requires a different design model. In the event-driven WSN, the sensors send data only when certain events occur. Normally, the sensors do not have much data to send. When an event occurs, many sensors in the network sense this event and send an alert to the sink at the same time. These alerts are often redundant and the sensors waste energy transmitting redundant information. In WSN, over-hearing is often considered a cause of energy waste. However, in the event-driven wireless sensor network, we show that over-hearing can be an efficient method to reduce redundant communication in sensor networks. Hence, it can save energy and extend the lifetime of sensor networks.

Key words:
energy efficiency, medium access control, over-hearing, wireless sensor networks.

1. Introduction

ver the past few years, we have observed a boost in the development of wireless network techniques. Since the advent of the mobile network, WIFI and ad-hoc network, research in wireless networks has focused much more on wireless sensor networks. A wireless sensor network is a network composed of hundreds to thousands of communicating sensors and deployed in an area to collect environment events. In a sensor network, each node is a small sensor with a low capacity of processing, storage and energy. The sensors are often battery powered and we expect a lifetime of several months to several years. Hence, the major difference between the components of the sensor network and the components of the traditional wireless network is that in a sensor network, it is difficult (even impossible in certain cases) to change the battery. In the future, when sensor manufacture becomes massive, sensor price will be much lower and it is preferable to change sensors rather than batteries after use.

These particular characteristics of the sensor network change its performance policy in comparison to that of traditional wireless networks. In traditional wireless networks, the most important performance criterion is fairness. The objective is to guarantee that all the nodes in the network are equal and have the same probability of accessing the channel. On the contrary, in the wireless sensor network, since we want to maximize the network lifetime, energy consumption becomes the primary concern while the other criteria like fairness, throughput and band-width become secondary. Energy is used mainly for communicating and processing data. According to [1], communicating 1 KB of data by 100m consumes as much energy as processing 3 million instructions. So, it is preferable to process the data locally rather than to communicate between sensors.

Indeed, when sensors communicate, there is always energy waste. In [2], W. Ye et al have identified 4 reasons for energy waste. First, the collision occurs on the recipient when two or more interfering nodes transmit a packet at the same time. This collision implies a retransmitting messages and increases energy consumption. The second reason is over-hearing, where a node listens to the messages which are not destined to it. In wireless networks, a node often listens to the communication of others in order to know the end of that communication so that it can avoid transmission during another communication. In addition, message controls like Request to Send (RTS), Clear to Send (CTS) are also a source of energy waste. Finally, idle listening is the time when a node listens to the channel to wait for a possible incoming packet. In this case, the node must switch its radio on and if there is no transmission to it, energy is wasted.

Normally, a sensor radio has 4 operating modes: transmission, reception, idle listening and sleep. MICA [3] is a typical example, whose levels of energy consumption are illustrated in table 1. In many cases, energy consumption in listening mode and idle mode is approximately equal, and half of the energy used in transmission mode. On the contrary, the energy consumption in sleep mode is much lower. Hence, we should put the radio in sleep mode as much as possible.

Manuscript received March 20, 2007
Manuscript revised March 25, 2007

Table 1: Mica sensor's specification

State	Energy consumption(mW)
Transmission	80
Reception / Idle	30
Sleep	0.003

Generally, there are three models of WSN: *continuous*, *on-demand* and *event-driven*. In continuous WSN, the sensors send data periodically to the access point. It is always the sensors in the network which initiate the communication. In the on-demand WSN model, the sensors send data only when they receive a request from the access point. However, we are interested in the last model: event-driven WSN. In this model, the sensors send data only when certain events occur. For example, a sensor network is deployed in a forest to detect the fire. Normally, when the temperature is low, the sensors sense the temperature, but they do not transmit this information. They send data only when they find that the temperature is high (more than 100°C). Another example is a sensor network deployed in a production chain in a manufactory. Sensors silently sense information: vibration, humidity etc. Sensors send alert only when they find any problems in the factory. In this kind of network, the number of nodes is very large: from hundreds to a thousand nodes which are often deployed randomly and densely. In a forest sensor network application, we cannot imagine someone walking in a big forest, deploying each sensor among the trees. Hence, a good solution would be to have a plane fly over the forest and drop sensors into it. The sensors automatically organise to a connected network. Moreover, in the event-driven WSN, sensors are often deployed densely to guarantee network coverage and fault tolerance. If there is a fault in any node, the network will always be covered and managed by the remaining nodes.

When an event occurs, because the sensor network is deployed randomly and densely, many sensors collect the same information and send it to the access point. In a fire detection sensor network, if there is a fire, many sensors will collect the same temperature and send it to the access point. Firstly, they lose energy sending redundant data. Secondly, since there are many transmissions at the same time, the network contention increases, which is likely to generate more collisions in the network.

These problems prompted us to propose a new MAC protocol specific to the event-driven WSN. The main aim of our technique is to reduce the number of redundant communications. By doing so, we can subsequently reduce collisions and energy waste in the network and therefore maximizes its lifespan.

2. Related works

Today, research on the medium access control of wireless sensor networks is very prolific. There is a clear attempt to improve MAC protocol management of communication time between sensors which consumes the most energy. According to various characteristics, we classify MAC protocol into two different types: *Contention-Based* and *Contention-Free.*

Contention-free MAC is based on reservation and scheduling. Here, each node announces a time slot that they want to use to the coordinator of the network. This coordinator schedules the request and allocates to other nodes their respective time slots. In this way, a node can access the channel without colliding with others because it is the only node which can transmit during its time slot. Bluetooth [4], TRAMA [5] and LEACH [6] are examples of this type of MAC.

This technique guarantees low energy consumption because each node in the network works only in its time slot without collisions. However, the main drawback of this technique is that it does not adapt well to topology change and is therefore non-scalable. Any addition or deletion of a node implies a time slot rescheduling for all the nodes in the cluster. Moreover, the nodes must be well synchronized among them (about several μs), which is not easy to achieve in the widely distributed and scalable environment of a sensor network.

Unlike this technique, *contention-based MAC* is a protocol where every node competes to access the channel. Before transmitting a message, a node listens to the channel to see whether there is already a transmission in the medium. If the channel is busy, it will wait for a random time and retry to detect it later. If the channel is free, it will transmit the message. Collision occurs when two or more interfering nodes observe that the channel is free at the same time and they transmit their message simultaneously. In this case, the receivers obtain a noise signal which does not contain any information and that implies a retransmission.

The most well-known example of this technique is protocol IEEE 802.11 [7] for wireless LAN network. Indeed, this technique works well when the communication occurs between personal computers or pocket PCs, where energy consumption is not a major concern. This protocol does not take into account methods to save energy. However, in a wireless sensor network, the devices are small sensors and very sensitive to energy consumption. Therefore, the MAC protocol of IEEE 802.11 is not suitable for sensor network.

As stated earlier, the sensor idle mode consumes a lot of energy. Many research projects have been carried out to optimize the existing MAC methods and better adapt them to the sensor networks. S-MAC [8] is considered to be the first MAC protocol proposal which tries to reduce idle time for sensors. In S-MAC, the nodes are periodically set to listen and sleep mode, where the listen time is approximately 10% of the sleep time. In listen mode, the sensors exchange their schedule and control packet in order to reach an agreement between sender and receiver. A node switches to sleep mode when it does not have any messages to send or to receive, and it switches its radio on to transmit or receive messages. Hence, the sensors might save up to 90% of energy compared to the previous protocols. However, S-MAC is preferable for continuous WSN where sensors send data regularly. They use packet controls RTS, CTS to avoid the hidden terminal problem. These packet controls create a network overhead and increase energy consumption. Moreover, S-MAC makes a trade-off between latency and energy consumption. In an event-driven WSN, because there is a lot of redundant information, we do not need to receive information from every node in the area where the event takes place. For example, if 10 nodes detect a fire in an area, it is enough for us to receive 3 alerts for the fire, but not all 10 alerts from 10 nodes. Therefore, S-MAC is not well adapted to event-driven WSN.

To the best of our knowledge, SIFT [9] is the only related work for MAC protocol specific to event-driven WSN. The main objective of SIFT is to guarantee successful transmission of R/N (R<N) messages in the shortest delay. Like S-MAC, the contention window of SIFT is fixed. However, SIFT chooses the time slot to access the channel in a non-uniform way. So it can adapt to different congestion levels. The disadvantage of this technique is that it is sensitive to the change of the number of nodes in the network. In fact, the distribution function is based on the number of sensors in the network. If the number of sensors changes, there may be more collisions and the sensors consume even more energy. Moreover, the distribution function is complicated and requires a lot of processing to compute the non-uniform probability for each transmission. Based on the same principle, CSMA/p * [10] is proposed where *p** is a non-uniform distribution in order to minimize latency.

3. System model

In this section, we will describe a new MAC protocol for event-driven WSN. This new MAC protocol guarantees low cost communication and a short delay between sensors and access point. We suppose several hypotheses for the context of the sensor network. Firstly, the wireless sensor network is an event-driven WSN, so it is dense with several hundreds to thousands of sensors deployed randomly in an area to detect an event relating to the environment: the temperature, moisture, pressure, vibration etc. Secondly, when an event occurs, many sensors detect the same information and transmit it to the access point. So the sensors waste energy to transmit redundant messages. Based on these hypotheses, we present our proposal to better adapt to event-driven applications. Our proposal reduces energy waste by reducing the amount of redundant communication and guarantees a short communication delay. Thus, our following proposal is well adapted to event-driven WSN.

3.1 Network organisation

We start to describe our proposal by introducing the network organisation. After being deployed in an area, the sensors are organised automatically into a hierarchical network (Fig. 1) in order to send alerts to the access point. There are three types of node: normal node, gateway node and access point. Normal node only senses ambient information. Gateway node can sense ambient information and route packet. Access point collects and process information sent from sensors. The network organisation is referenced in many existed work. Hence, we suppose that nodes use an existed technique to know whether it is the normal node or gateway node. This network can be organised into multiple tiers with multiple gateway nodes. Fig. 1 illustrates a three tier hierarchical network. When there is an event in an area, every node senses this event, creates an alert packet and sends this event to the sink via gateway node. The gateway node forwards the packet to the access point. If the network organisation has multiple tiers, the gateway node forwards packet to another gateway node until the packet reaches the access point.

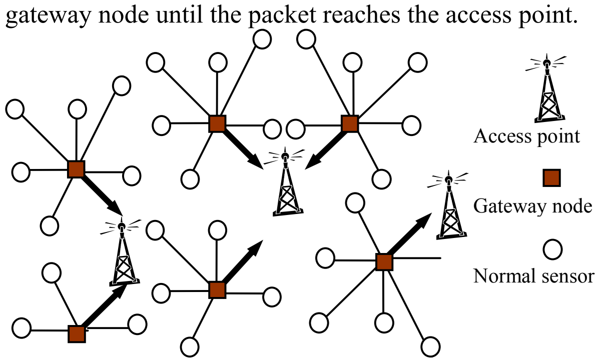

Fig. 1: Hierarchical network

For example, in a fire detection application, after being dropped from the plane, every sensor in an area organise in hierarchical network. Sensors establish a route to the nearest sink via gateway nodes. In a forest, there may be several base stations, where we can find forest keeper. The goal is that they are in the area and they can react to the fire quickly. Once a fire occurs, sensors detect this environment change and send information to the gateway node. Gateway node in turn forwards the alert to another gateway node until the packet reaches a base station.

3.2 A new MAC technique for event-driven wireless sensor network

As stated earlier, S-MAC is not well adapted to event-driven WSN due to the fact that it creates overhead for the network. However, the idea of S-MAC to periodically listen and sleep and to synchronise between nodes is very interesting. Our proposal takes inspiration from their ideas. However, we have adapted them to the new requirements of event-driven applications.

Fig. 2: Periodically listen and sleep

In our approach, every node listens and sleeps periodically. In order to synchronise between sensors, the forward sensor broadcasts its schedule to its children by sending a SYNC packet. Hence, the children nodes know when to wake up to work with the gateway node and when to go to sleep to save energy. Each node listens and sleeps periodically as illustrated in Fig. 2. Here, the gateway node sends its SYNC packet at the SYNC interval. Its children listen to the SYNC packet in this interval to synchronise with the gateway node. In the SYNC period, because only the gateway node transfers and every children node listen, there is no contention period. Otherwise, in the sleep period, the node can set to one of 4 modes: transmission, reception, overhearing or sleep. If it has an alert to send, it comes to a contention period to access the channel. After the SYNC period, if many children nodes want to transmit their packet and they start to transmit right after the SYNC period, there will be a collision. Hence, after the SYNC period, each node accesses the channel in contention. It chooses a time slot in a contention window and does a carrier sense in the channel in order to know whether some other nodes have won the channel before. If it does not find any transmission in the channel, it changes to transmission mode and starts to transmit its packet. The gateway node changes to reception mode and receives the packet.

In S-MAC, the node that loses the channel goes to sleep to save energy and wakes up in the next period. This is a good method to save energy in a continuous WSN, where we need all information sent by every node in the network. However, in event-driven WSN, the nodes in the same area probably sense the same information. Hence, all the nodes in a given area sense the same information and send the same alert to the sink. This results in transmission waste. That is the reason why we propose an overhearing technique in order to avoid these redundant transmissions. The principle of our approach is that *before transmitting an alarm, a node overhears its neighbours to see whether this alarm has already been sent.* So the node does not retransmit a message which has already been sent by one of its neighbours. Hence, the node which loses the channel changes to overhearing mode and the node which has no packet to send goes to sleep mode.

If an over-hearing sensor receives a message which contains the same information that it wants to send to the same destination (Ex: the sink), it will remove its message because the same information has already been sent by one of its neighbours. If the overhearing sensor finds that the overhearing packet that it has heard is not similar to its packet, it will switch its radio off and try to send its packet later. In fact, we can easily see that the number of transmissions in the network is proportional to the number of collisions. By using our proposal, we reduce not only the number of transmissions but also the number of collisions. So energy consumption is reduced and the network has a longer lifetime. If there are many redundant transmissions in case of an event-driven application, our approach is clearly advantageous.

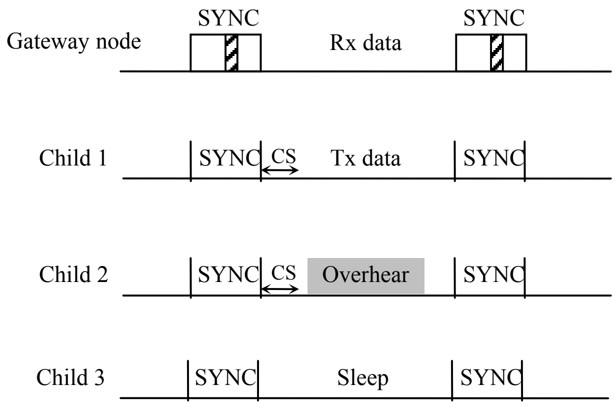

Fig. 3: A new MAC technique for event-driven WSN

Fig. 3 illustrates a communication between 4 nodes: 3 children and 1 gateway node. We will see that each node has a specific mode after the SYNC period. Here, two children (1 and 2) detect the event at the same time and want to transmit to the sink (via the gateway node) simultaneously. Child 3 does not detect this event. After the SYNC interval, children 1 and 2 go to contention period because they want to transmit their packets. Child 3 goes into sleep mode because it does not have anything to transmit. Suppose that child 1 wins the channel and transmit its packet. In this case, child 2 continues to set its radio on to overhear the communication between child 1 and the gateway node. Indeed, it sets its radio in promiscuous mode to receive all the packets, even those which are not for him. Child 2 analyses the packet that it has overheard. If this packet has the same destination address (the access point), and the same information (the same temperature), it will destroy its own packet.

In fact, in a sensor network, the neighbouring nodes do not often sense exactly the same information. For example, in a fire detection application, when there is a fire, the neighbouring nodes do not often sense exactly the same temperature. One can sense a temperature of 150°C while its neighbouring node senses 153°C. However, as they are spatially related, they always detect the approximate value. So, we consider "the same information" as "the approximate information". We define a threshold Δ for each value type. For example, we set value Δ = 5 for the temperature. Hence, two temperature values are considered the same if the difference between them is less than 5. Let us come back to Fig. 3, when child 1 sends a temperature T_1=100°C, child 2 overhears this value and if it has the temperature T_2=104, it consider that it has the same information because $|T_2 - T_1| < \Delta$. Hence, it cancels its transmission.

Moreover, if child 2 analyses the packet that it has overheard and it finds that the destination address is not the same, or the information is not the same, it will go to sleep immediately to save energy. Hence, a node will not overhear the overall transmission if it does not have the same alert and the same destination address.

By setting the sensors in reception mode, the sensors consume energy to receive the messages destined to others. And that is one of the reasons for energy waste "overhearing" mentioned in [2]. Here, we give a new look to "overhearing" mode. Instead energy waste, by using "overhearing", we can save energy by reducing the transmission of redundant messages. There are several reasons which prove the effectiveness of our approach. First, energy consumption in reception mode is normally lower than in transmission mode [7]. Second, the node is set in overhearing mode if and only if it wants to send a packet and it has lost the medium. Moreover, if the node does not have the same information and the same destination address, it will not overhear the entire transmission. Third, in event-driven applications, the probability that many nodes observe the same event is high. Hence, our approach obviously reduces the number of redundant transmissions.

3.3 Influential range

In fact, the radio range is large: 100m in WIFI [6], 50-70m in Zigbee [11]. If a wireless sensor network applies our proposal directly, there will probably be errors and fault tolerance problems. Suppose that all nodes are interfering. If one node sends a packet, all the others can over-hear this packet. First, the technique presented in section B is not fault tolerance because if there is an event, many nodes detect this event and only one alert is sent to the sink (since every interfering node overhears this alert and cancels its transmission). Second, an error might occur when there are two events with the same information. Fig. 4 illustrates this case where the sources of alarm are different. Here, the nodes on the left detect the left event while the nodes on the right detect the right event. Suppose that one node on the left wins the channel and sends its packet to the sink. Every node overhears this information and since two events have the same information, they remove their own packets. The result is that the sink receives only a message from the event on the left and it does not have any information on the event about the right. That is an error case that we need to avoid.

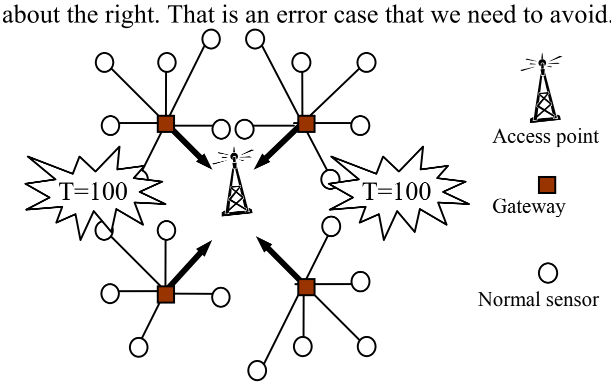

Fig. 4: One event is detected

To solve this problem, we refine our approach by taking the radio range into account. We define a new concept that we call *influential range*.

Definition: *Influential range* is a range where nodes are likely to observe the same information.

This range is different from the radio range, and it is always shorter than the radio range of the node (Figure 5). We refine the overhearing technique as follows: "*A node applies our method if and only if it is in the influential range of the transmitting node*". Hence, only nodes in the area where the event has took place, overhear each other. By limiting the range in influential range, we can avoid two problems mentioned before.

Therefore, influential range decides whether a node is set to overhearing mode. But, how can a node know if it is in the influential range? *Indeed, in our approach, the influential range of a node is defined by the transmitter node.* When the sensors communicate, the sensor which is nearer the transmitter receives a stronger signal than a more remote node. The received signal strength is inversely proportional to the distance between the transmitter and receiver. If the distance is long, the received signal strength is weak and vice versa. In Fig. 5, suppose node A wins the channel and transmits its packet. Because AB<AC, the signal strength received in B is stronger than in C. A node can easily obtain the received signal strength by using a circuit Received Signal Strength Indicator (RSSI). From this value, a node can estimate its distance to the transmitter.

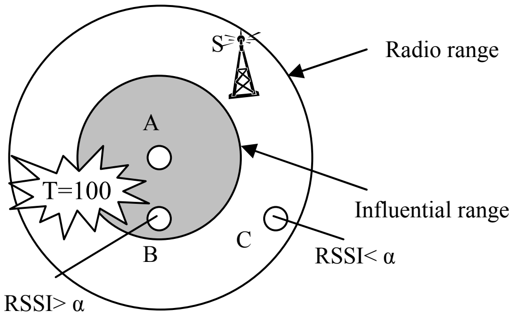

Fig. 5: Influential range

We define a threshold α of the received signal strength to determine the influential range of a node. If a node receives a packet at signal strength greater than α, it knows that it is in the influential range of the transmitter. Otherwise, it is outside the transmitter influential range.

In Fig. 5, when nodes B and C have lost the channel, they hear the transmission between A and the access point. They compute the received a signal strength to know whether they are in influential range. Node B finds that the received signal power is higher than the threshold α, so it knows that it is in the influential range of node A. Hence, it sets its radio in overhearing mode to overhear the packets of A (even though it is not the recipient of the transmission). Since it finds that node A sent a message to the sink with the same information that it wants to send to the sink, it removes its packet because it is redundant message. However, the node C finds that the received signal power is lower than α, it knows that it is not in the influential range of A and its alarm is likely to come from another source. It switches its radio off to save energy. So, node C does not overhear the transmission between A and the sink and it will transmit its packet in the next period.

3.4 A complete transmission scenario by using the overhearing technique

In the previous section, we mentioned two problems if we apply the overhearing technique directly. In this section, we will specify how the influential range can improve our technique and avoid these problems. Fig. 6 illustrates a complete transmission scenario by using the overhearing technique. In this area, there are 12 sensors. When there is an event (T=100°C), every node senses this event and sends an alert to the access point via the gateway node. So by default, there will be 12 transmissions to the gateway node. By using the overhearing technique, we can reduce the number of transmissions. If we do not apply the influential range, there will be only one transmission because as one node transmits, the others overhear the transmission and cancel its packets. With the influential range, we reduce the number of transmissions to a certain number (but not to 1 transmission). So we reduce the energy consumption while guarantee the fault tolerance of the system.

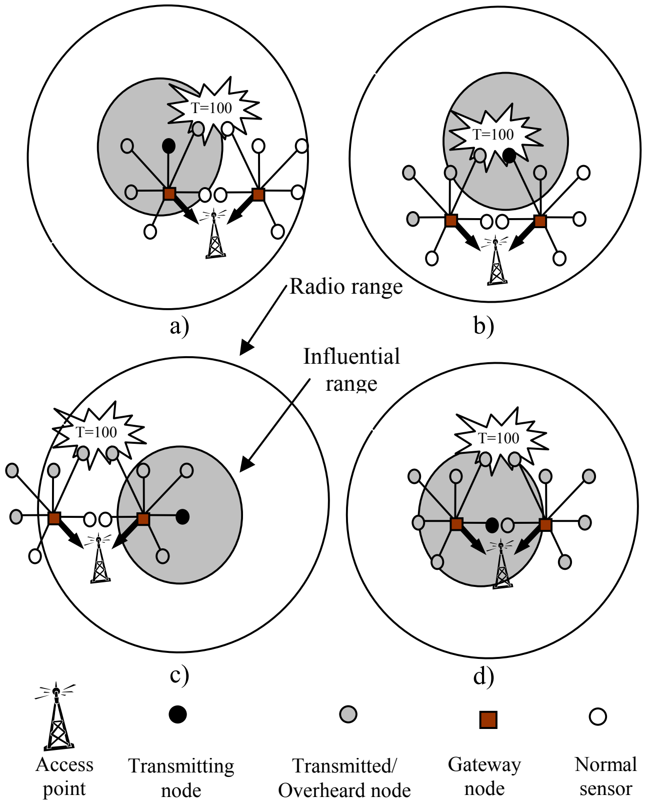

Fig. 6: Transmission scenario
a) 1st period ; b)2nd period; c) 3rd period; d) 4th period

In this example, every node senses this event and goes to contention period. Fig 6a illustrates the first transmission where the black node wins the channel and transmits to the gateway node. Here, three grey nodes are in the influential range of the black node (in the grey circle), so they overhear this transmission. Because they have the same information to send to the sink, they cancel their transmission. For the first step, we save 3 transmissions. The other nodes are not in the influential range of the black node, they go to sleep in this period to save energy. Fig. 6b, c, d illustrate the second, the third and the fourth transmission. In each transmission, the overhearing procedure in the influential range is repeated. In the second period, we save 1 transmission. In the third period, we save 2 transmissions and in the last period, we save 2 transmissions. Therefore, with 4 alerts, the access point already has enough information about the event. We reduce the number of transmissions from 12 to 4 and therefore we save 8 transmissions.

4. Experimental Evaluation

In this section, we will present the results of performance evaluation to prove the effectiveness of our proposal.

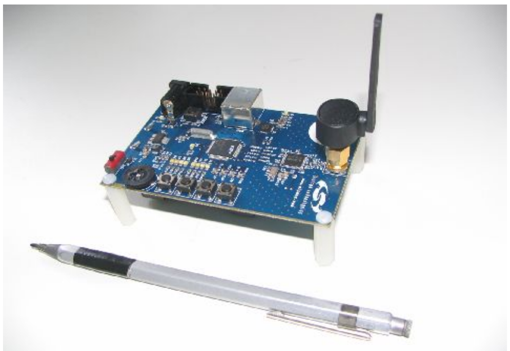

Fig. 7: A Silicon sensor

To measure the relation between received signal strength and distance, we used the Silicon sensors [12] to determine the influential range. Each sensor is equipped with a C8051F121 micro controller and a Chipcon CC2420 RF Transceiver antenna (Fig. 7). The micro controller includes a CPU 8051 100 MIPS, a memory flash 128 KB and a RAM 8KB. The Chipcon CC2420 antenna is composed of a transceiver 2.4 GHz and Dual 128 bytes FIFOs.

In the first experiment, we measure the influential range. In fact, this range is different from one application to another. We measured of the received signal strength by varying the distance. The test was made by 5 sensors. By using this result, one can define the threshold α to determine the radius of the influential range.

Table 2: Rssi value (dbm) corresponding to the distance

Node / Distance (cm)	1	2	3	4	5
10	-17	-17	-17	-17	-17
20	-23	-22	-24	-23	-24
40	-26	-27	-27	-28	-27
80	-38	-37	-39	-37	-38
160	-46	-50	-44	-52	-47

Table 2 illustrates the test result of the received signal strength according to different distances. The result shows that the received signal strength is inversely proportional to the distance. We can use this table to determine threshold α. Example: in an application, we find that the nodes in a radius of 80cm are likely to observe the same event. Consulting Table 2, we find that this distance corresponds to the received signal strength of -38dBm. Hence, we can assign the value of α = -38dBm. In this case, when a node receives signal strength lower than -38dBm, it knows that it is not in the influential range of the transmitter and switches its radio to sleep mode. Otherwise, it sets its radio in reception mode to overhear the transmission. In each WSN application, we will have different influential range values. With a forest monitoring application, this range is long (several meters). However, with a machine monitoring application, this range must be shorter (several centimetres) because sensors are deployed more densely in this type of application.

In fact, for this kind of sensor, RSSI value is uniform when the distance between sensors is less than 2 meters. Hence, the use of influential range is effective in a small range (<2m). Beyond 2 meters, the RSSI value is non-uniform, and we cannot use this value to estimate the distance between sensors. However, in many event-driven WSN, the alarm is often caused by the same event only in a small area, so our proposal provide an effective means of reducing both redundant transmission and energy consumption for event-driven WSN.

Next, we compare the energy consumption of our approach to that of S-MAC by varying the number of nodes in the influential range between 1 and 10 nodes. We measure the energy consumption of the MICA sensor whose specification is illustrated in table 1.

In this evaluation, the sensors are deployed in a small area where every node is interfering and observes the same event. Suppose that listen period is 100ms and sleep period is 900ms. We obtain the energy consumption in Fig. 8.

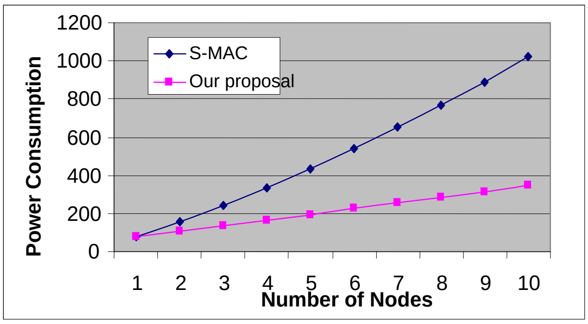

Fig. 8: Power consumption for our proposal vs S-MAC

The horizontal axis is the number of nodes in the influential range. The vertical axis is the overall power consumption to send an event to the sink. By observing the curves, we can see that our proposal clearly improve power consumption. The more nodes there are in the influential range, the more energy the sensor network saves. Indeed, the reason why the sensors in S-MAC consume more energy is that in S-MAC, when an event occurs, all the sensors collect the same information and send the same information to the sink. While in our approach, by using the overhearing mode, the sensor nodes can avoid transmitting redundant messages and can save energy.

5. Conclusion

In this paper, we have presented and analysed a new MAC protocol adapted to event-driven WSN. This protocol avoids redundant transmission and is energy-efficient. This paper improves our existing proposal presented in [13]. It is better adapted to event-driven WSN because it guarantees the least overhead created by message controls in a hierarchical topology.
We have shown that overhearing is not always a cause of energy waste but can actually save energy. With a new notion "influential range", we guarantee the fault tolerance of the system where we cancel only redundant transmission. Our proposal works well with hierarchical topology and offers a good latency for event-driven wireless sensor network. By evaluation, we have demonstrated that our proposal reduces considerably power consumption, especially in the event-driven wireless sensor network where there are many redundant transmissions.

Acknowledgments

We would like to express our thanks to the Franche Comté region for their financial support for our research at the Franche Comté University, Besançon, FRANCE.

References

[1] G.J Pottie and W. J. Kaiser. Embedding the Internet: Wireless Integrated Network Sensors. Communications of the ACM, 43(5), (2000), pp. 51-58.

[2] W. Ye, J. Heidemann, D. Estrin, "Medium Access Control With Coordinated Adaptive Sleeping for Wireless Sensor Networks", Volume: 12, Issue: 3, June 2004, pp. 493-506.

[3] MICA2 Mote Datasheet, http://www.xbow.com/Products/-Product_pdf_files/Wireless_pdf/6020-0042-01_A_MICA2.pdf.

[4] Specification of the Bluetooth System: Core (2001). [Online]. Available http://www.bluetooth.org/

[5] V. Rajendran, K. Obraczka, J.J. Garcia-Luna-Aceves, "Energy-Efficient, Collision-Free Medium Access Control for Wireless Sensor Networks", Proc. ACM SenSys 03, Los Angeles, California, November 2003, pp.181 - 192.

[6] W. R. Heinzelman, A. Chandrakasan, and H. Balakrishnan, "Energy efficient communication protocols for wireless microsensor networks," in Proc. Hawaii Int. Conf. Systems Sciences, Jan. 2000, pp. 3005–3014.

[7] Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specification, IEEE Std. 802.11-1999 edition.

[8] W. Ye, J. Heidemann, D. Estrin, "Medium Access Control With Coordinated Adaptive Sleeping for Wireless Sensor Networks", IEEE/ACM Transactions on Networking, Volume: 12, Issue: 3, June 2004, pp. 493 – 506.

[9] K. Jamieson, H. Balakrishnan, Y. C. Tay. Sift: a MAC Protocol for Event-Driven Wireless Sensor Networks. Proceedings of the Third European Workshop on Wireless Sensor Networks (EWSN), February 2006, pp. 260-275.

[10] Y.C. Tay, K.Jamieson, H.s Balakrishnan, "Collision-minimizing CSMA and Its Applications to Wireless Sensor Networks", IEEE Journal on Selected Areas in Communications, Volume: 22, Issue: 6, Aug. 2004, pp. 1048 – 1057.

[11] Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (LR-WPANs), IEEE Std. 802.15.4. October 2003 edition

[12] 2.4 GHz 802.15.4/Zigbee Development Board Hardware User's Guide. Avalalable: http://www.silabs.com/public/documents/

[13] H-C Le, H. Guyennet, N. Zerhouni, "Over-hearing for Energy Efficient in Event-Driven Wireless Sensor Network". In First IEEE International Workshop on Intelligent System Techniques for Wireless Sensor Networks (IST-WSN), Vancouver, Canada, Oct, 2006

Hung-Cuong LE received the B.S. degree in Computer Science from Hanoi University of Technologies in 2004, and M.S. degree in Computer Science from Paris VI University in 2005. He is currently a Ph.D. candidate at Franche Comté University, France. His research interests are protocols of medium access control for wireless sensor networks.

Hervé Guyennet is Professor of Computer Science at the University of Franche-Comté (Besancon – France). He received a PhD in 1985 and a "Habilitation à diriger des Recherches" in 1994 from the University of Besançon. He became Professor at the University of Franche-Comté in September 1995.
He is working on distributed systems: load balancing, cooperative work, distributed platform, multimedia, quality of service in networks, middleware.
He is the head of the "Network and Distributed Systems" group at the LIFC, the research laboratory for computer science at the university.
He has been the scientific advisor for 15 thesis and has published more than 80 papers

Noureddine Zerhouni is Professor in « Ecole Nationale Supérieure de Mécanique et des Microtechniques de Besancon » in France.