Performance Evaluation of WideMac Compared to ALOHA in term of Energy Consumption for IR-UWB based WSN

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***Abstract*—The introduction of the IR-UWB Technology in the field of WSN was promising for researchers especially for its low power consumption feature. To implement such a solution, we need a suitable MAC protocol to exploit the specific features of this technology. When introducing this Technology, ALOHA was the only candidate MAC protocol. Because of the high energy consumption of ALOHA, in this paper we present WideMac, a low power medium access control protocol designed specifically for Impulse Radio Ultra Wide Band transceivers. The IR-UWB channel offers ultra low power transmissions and unmatchable robustness to multiple access interference. WideMac takes advantage of these two key properties by using asynchronous periodic beacon transmissions from each network node.**

To test and evaluate the performance of WideMac protocol we used PhyLayerUWBIR class developed under MiXiM platform on OMNet++ as a physical layer. For the MAC layer we developed our own class WideMacLayer.

***Index Terms*—WSN, IR-UWB, ALOHA, WideMac, Power Consumption, OMNet++, MiXiM.**

I. Introduction

Wireless Sensor Networks (WSNs) is one of the most interesting networking technologies since its ability to use no infrastructure communications, it have been used for many applications, including military sensing, data broadcasting [1], environmental monitoring [2], Intelligent Vehicular Systems [3], multimedia [4], patient monitoring [5], agriculture [6], industrial automation [7] and audio [8] etc. This kind of networks has not yet achieved widespread deployments, though it has been proven able to meet the requirements of many classes of applications. Wireless sensor nodes have some limitations as lower computing capabilities, smaller memory devices, small bandwidth and very lower battery autonomy; these constraints represent the main challenges in the development or deployment of any solution using WSNs. Energy consumption is a very important design consideration in WSNs, New wireless technologies emerge in the recent few years, providing large opportunities in terms of low power consumption, high and low rate and are promising for environment monitoring applications. IR-UWB technology is one of these new technologies and is considered as a next generation of the IEEE802.15.4 standard; it is a promising solution for WSN due to its various advantages such as its robustness to severe multipath fading even in indoor environments, its potential to provide accurate localization, its low cost and complexity, and low energy consumption [9]. It is necessary to find a very adapt MAC layer protocol to this Technology for keeping his advantages.

The present paper is organized as follows. In Section 2 we introduced Wireless Sensor Networks. In section 3 we presented the IR-UWB technology. Section 4 presents the ALOHA MAC protocol. In section 5 we presented WideMac. The simulation and its results are presented in section 6; finally, Section 7 concludes the paper.

II Wireless Sensor Network

A wireless sensor network (WSN) in its simplest form can be defined as a network of (possibly low-size and low complex) devices denoted as nodes that can sense the environment and communicate the information gathered from the monitored field through wireless links; the data is forwarded, possibly via multiple hops relaying, to a sink (Base Station) that can use it locally, or is connected to other networks (e.g., the Internet) through a gateway (see Figure 1).

- The nodes can be stationary or moving.
- They can be aware of their location or not.
- They can be homogeneous or not.

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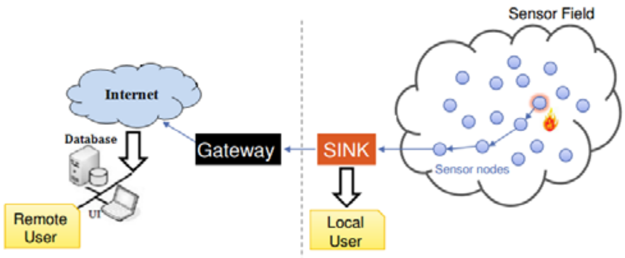

Figure 1: Sensor network architecture.

2.1 *Sensor Node Architecture*

A wireless sensor network (WSN) in its simplest form can be defined as a network of (possibly low-size and low complex) devices denoted as nodes that can sense the environment and communicate the information gathered from the monitored field through wireless links; the data is forwarded, possibly via multiple hops relaying, to a sink (Base Station) that can use it locally, or is connected to other networks (e.g., the Internet) through a gateway (see Figure 2). The nodes can be stationary or moving. They can be aware of their location or not. They can be homogeneous or not.

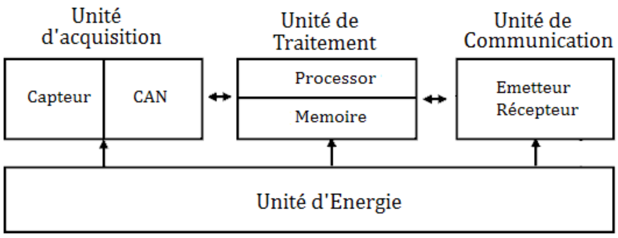

Figure 2: Sensor node architecture.

2.2 *Wireless Technologies*

Many wireless technologies are used in WSN; the most frequently used are ZigBee, the various forms of IEEE802.11 or Wi-Fi, Bluetooth, and UWB with the two standards IEEE802.15.3a/4a. The first standard for wireless local area networks (WLAN) was the IEEE802.11 specification in 1997. For applications requiring high data rate, the 802.11n standard is under development to achieve more than 100 Mbits/s. Recently Wi-Fi is widely adopted in various applications and due to its complexity and higher energy consumption compared to ZigBee and IR-UWB, this technology has been applied only to perform some particular functions in WSN [10].

III IR-UWB

Impulse Radio Ultra Wide Band (IR-UWB) is a promising technology to address Wireless Sensor Network constraints. IR-UWB signals are transmitted in form of very short pulses with low duty cycle (see Figure 3). The medium is divided into frames and each frame is shared in N_h chips. The frame and chip duration are T_f and T_c, respectively. The transmitted symbol can be repeated following a pseudo random sequence to avoid catastrophic collision under multiuser access conditions [11].

Using the Time Hopping Binary Pulse Amplitude Modulation (THBPAM) scheme for example, the kth user transmitted signal $S_{tx}^{(k)}(t)$ can be expressed as:

$$S_{tx}^{(k)}(t) = \sum_{j=-\infty}^{+\infty} \sqrt{\mathrm{E}_{\mathrm{tx}}}\, X_{tx}\left(t - j\,.T_f - C_j^k.T_c\right)$$

Where E_{tx} is the transmitted pulse energy; $X_{tx}(t)$ denotes the basic pulse shape and C_j^k represents the j^{th} component of the pseudo random Time Hopping Sequence. The received signal r(t) when only one user is present can be expressed as:

$$r(t) = A.S_{tx}(t-\tau) + n(t)$$

$$r(t) = \sum_{j=-\infty}^{+\infty} A.\sqrt{\mathrm{E}_{\mathrm{tx}}}\, X_{tx}\left(t - j\,.T_f - C_j^k.T_c - \tau\right) + n(t)$$

where represents the pulse propagation delay and n(t) is Additive White Gaussian Noise (AWGN) with $N_0/2$ power density and *A* represents the attenuation the signal experiences during propagation [11]. It depends on the considered channel model in terms of path loss, multipath, shadowing. In a multi user scenario where N_u users are active, the received signal is expressed as

$$r(t) = \sum_{k=1}^{k=N_u} A_K\,.S_{tx}\left(t-\tau_k\right) + n(t)$$

$$r(t) = A_1\,.S_{tx}\left(t-\tau_1\right) + \sum_{k=2}^{N_u} A_K\,.S_{tx}\left(t-\tau_k\right) + n(t)$$

where τ_k represents the delay associated to the propagation and a synchronism between clocks. A_k represents the attenuation of the k^{th} user's signal (k=1 represents the signal of the user interest). This formulation can be used to characterize the TH-IR-UWB PHY layer in a multi user scenario and directly reports to the network simulator [4]; however the used propagation delay does not represent the real propagation delay for the real deployment configuration. The used Bit Error Rate (BER) versus the Signal to Interference and Noise Ratio (SINR) is also based on a perfect power control assumption which is not always realistic.

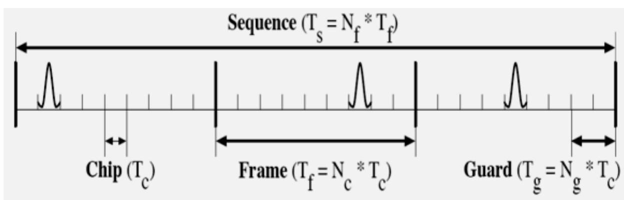

Figure 3: Classic IR-UWB signal and its parameters: Tc is the duration of a chip, Tf = Nc.Tc is the duration of a frame and Ts = Nf.Tf is the duration of a sequence. Tg = Ng.Tc is guard time used to prevent ISI.

IV ALOHA MAC PROTOCOL

ALOHA like Medium Access protocols for IR-UWB have shown their benefit [12]. A node immediately transmits once it has a packet to transmit without caring about the channel state (no need to Clear Channel Assessment: CCA). The MAC scheduler waits for the acknowledgement of the transmitted packet for a defined duration. When the acknowledgement is received before the expiration of this delay, it transmits the next packet. Otherwise, the transmitted packet must be retransmitted until the number of retransmission exceeds the retransmission limit.

4.1 ALOHA Throughput

The probability that n packets arrive in two packets time is given by:

$$P(n) = \frac{(2G)^n e^{-2G}}{n!}$$

Where G is traffic load.

The probability P(0) that a packet is successfully received without collision is calculated by letting n=0 in the above equation. We get:

$$P(0) = e^{-2G}$$

We can calculate throughput S with a traffic load G as follows:

$$S = G.P(0) = G.e^{-2G}$$

The Maximum throughput of ALOHA, shown in Figure 4 (*G=1/2)* is:

$$S_{max} = \frac{1}{2e} \approx 0.184$$

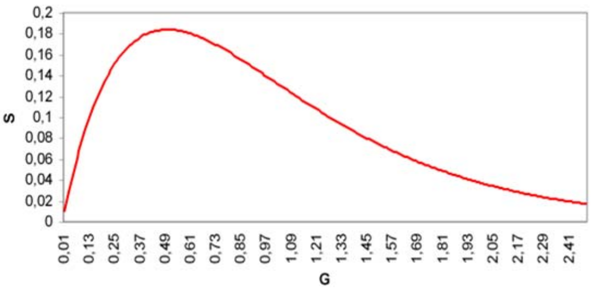

Figure 4: ALOHA throughput

4.2 Transition Diagram of ALOHA

With ALOHA the transmitter does not care about the channel state, once it has a packet to send, it transmits it on the medium, according to its own THS. As the received packets are not acknowledged here, no retransmission is needed. This protocol leads to low latency and gives a high priority to new events to be notified to the base station in a WSN application. It well suits applications where latency and new events notification is critical (see Figure 5).

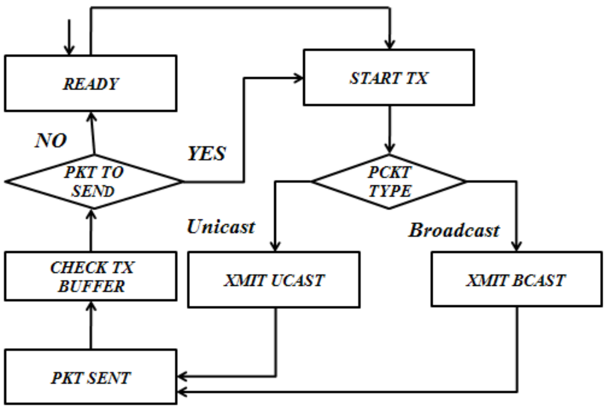

Figure 5: Transition diagram of ALOHA

V WIDEMAC

5.1 Presentation

WideMac was presented as a novel MAC protocol designed for wireless sensor networks using ultra wide band impulse radio transceivers. It makes all nodes periodically (period T_W, identical for all nodes) and asynchronously wake up, transmit a beacon message announcing their availability and listen for transmission attempts during a brief time T_{Listen}.

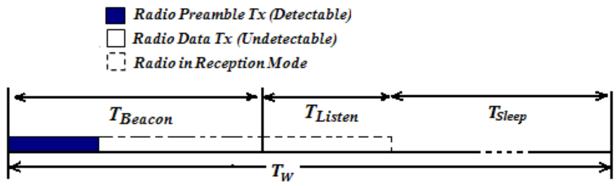

Figure 6: Detailed view of a WideMac period

Figure 6 illustrate a single period structure. It starts with a known and detectable synchronization preamble and is followed by a data sequence which announces the node address and potentially other information, such as a neighbor list or routing table information (for instance, cost of its known path to the sink). A small listening time follows T_{Listen}, during which the node stays in reception mode and that allows it to receive a message [13].

The whole period composed of T_{beacon} and T_{Listen} is called T_a (time of activity); and its very small compared to the time window T_W. This period is followed by a long sleeping period T_{Sleep} during which nodes save energy by keeping the radio in its sleeping mode.

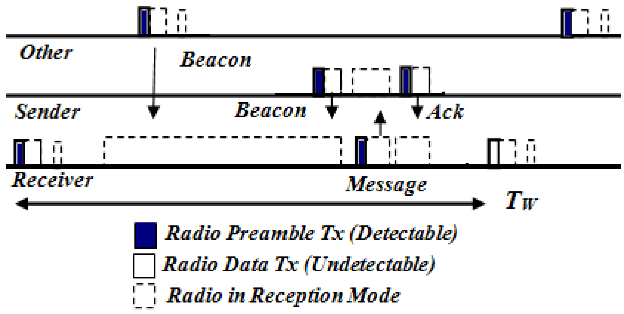

Figure 7: An initial WideMac data transmission.

When a node has a message to transmit, it first listens to the channel until it receives the beacon message of the destination node. This beacon message contains a backoff exponent value that must be used by all nodes when trying to access this destination. If this value is equal to zero, the source node can transmit immediately. Otherwise, it waits a random backoff time, waits for the destination beacon, and transmits its data packet. Because of the unreliability of the wireless channel, packets are acknowledged. If a packet is not acknowledged, or if the destination beacon was not received a retransmission procedure using the backoff algorithm is initiated, until the maximum number of retransmissions maxTxAttempts is reached.

The details of the backoff algorithm are described in subsection. Figure 7 depict a sender node listening to the channel, ignoring the beacon message of another node, and sending its message to the destination after receiving its beacon. The exchange ends with an acknowledgment message transmitted by the receiver node and addressed to the sender node [14].

5.2 WideMac Backoff Algorithm

The backoff algorithm has a major effect on collision, latency and fairness. WideMac periodic beacons allow the sender nodes to get some information on the channel state at the destination. This can be used to reduce the hidden and exposed terminal problems. The WideMac transmission procedure works as follows: a candidate sender node first listens for the receiver node's beacon. Once it finds it, it can either immediately attempt transmission (default for lightly loaded networks) or it can start a backoff timer before sending (this is activated by a flag always Backoff in the beacon). In both cases, the sender node waits for an acknowledgment. If it does not arrive, a retransmission procedure begins. The sender node chooses a random time parameterized by the receiver node's Backoff Exponent (BE) which was broadcast in the beacon, using a binary exponential backoff:

$$T_{Backoff} = N_{Backoff}.T_W,$$
$$where \quad N_{Backoff} \in [0, 2^{BE_{Receiver}} - 1].$$

The backoff time is thus a function of the wake-up interval T_W and of the channel state at the receiver node, as captured by $BE_{Receiver}$. Such a receiver-based backoff parameterization was also proposed in IR-MAC [15] . The use of a slotted backoff time based on T_W is natural since all candidate sender nodes are synchronized on the receiver node's wake up times: using a fraction of T_W would not change anything as the node would not transmit before receiving the destination beacon. Using an integer multiple of T_W for the unit backoff duration would increase latency and spread the traffic, but this can also be achieved by adapting the value of $BE_{Receiver}$ to the traffic conditions.

5.3 Power Consumption Models

Each normal T_W interval starts with a beacon frame transmission followed by a packet or a beacon reception attempt, during this start a node must enter transmission mode ($E_{SetupTx}$),transmit its beacon ($T_{Beacon}P_{Tx}$), switch to reception mode (E_{SwRxTx}) and attempt a packet reception ($T_{Listen}P_{Rx}$). These costs are regrouped in the beacon energy E_{Beacon}.

$$E_{Beacon} = E_{SetupTx} + T_{Beacon}P_{Tx} + E_{SwTxRx} + T_{Listen}P_{Rx}$$

In addition, during a time L, a node must sometimes transmit a packet E_{Tx} or receive one E_{Rx}, and sleep the rest of the time E_{Sleep}, resulting to the following average power consumption:

$$P_{WideMac} = \frac{1}{T_W}(E_{Beacon} + E_{Tx} + E_{Rx} + E_{Sleep})$$

Where:

$$E_{Tx} = K.C_{Tx}(P_{out}).V_B.T_{Tx}$$
$$E_{Rx} = K.C_{Rx}.V_B.T_{Rx}$$
$$E_{Sleep} = C_{Sleep}.V_B.T_{Sleep}$$

K represents the message length in bytes, P_{out} is the transmission power, C_{Tx}, C_{Rx} and C_{Sleep} represent the current intensities for the three modes, T_{Tx} and T_{Rx} are the time of transmission and reception.

VI Simulations and Results

6.1 OMNet++ and MiXiM Simulation Platform

OMNeT++ is an extensible, modular, component-based C++ simulation library and framework which also includes an integrated development and a graphical runtime environment; it is a discreet events based simulator and it provides a powerful and clear simulation framework.

MiXiM joins and extends several existing simulation frameworks developed for wireless and mobile simulations in OMNeT++. It provides detailed models of the wireless channel, wireless connectivity, mobility models, models for obstacles and many communication protocols especially at the Medium Access Control (MAC) level. Moreover, it provides a user-friendly graphical representation of wireless and mobile networks in OMNeT++, supporting debugging and defining even complex wireless scenarios [16].

6.2 Simulation Parameters

We performed the simulations in the MiXiM 2.1 release framework with the OMNeT++ 4.2 network simulator.

We used a grid network, where nodes transmit packets to a Sink node; also we ran several simulations with different nodes numbers and parameters values to evaluate our new protocol.

TABLE I:
ENERGY PARAMETERS

ıeter	
	0 mW
	mW
	mW
x	0 mW
x	mW
x	0 mW
x	0 mW

TABLE II:
TIMING PARAMETERS

ıeter	
$T_{SetupRx}$	0.000103 s
$T_{SetupTx}$	0.000203 s
T_{SwTxRx}	0.000120 s
T_{SwRxTx}	0.000210 s
$T_{RxToSleep}$	0.000031 s
$T_{TxToSleep}$	0.000032 s
Bit rate	0.850000 Mbps

For the energy consumption we used the following radio power consumption parameters shown in TABLE I. For the radio timing we used the parameters shown bellow in Table II.

6.3 Results

In this section, we present the results obtained using the timing and energy parameters cited in section 6.2. The low power consumption of WideMac was concretized by the results shown in Figure 8. It shows that the power consumption of WideMac protocols is remarkably less than the ALOHA MAC protocol. This factor (power consumption) is considered as a key factor for WideMac protocol since it influences directly the Networks life time.

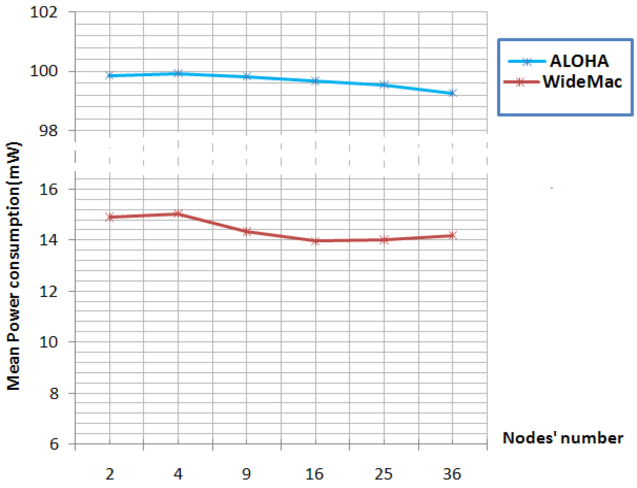

Figure 8: Nodes power consumption average

CONCLUSION

Power consumption was and is an interesting issue that is stills a factor in the development of WSN protocols especially in the physical and MAC layers; it is the primary metric to design a sensor node in wireless sensor network. The low power consumption is the main advantage of the WideMac protocol; it is also very close to an ideal energy consumption model for the IR-UWB based transceivers and gave a good result at this level. This result was achieved thanks to the fact that the network nodes are asleep in the T_{sleep} periods which occupy a wide range in the T_W periods.

We aim, as a future work, to develop a new adapted routing protocol that will be paired with WideMac to largely exploit the IR-UWB features.

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