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An Efficient Short Range Wireless Communication Technology for Wireless Sensor Network

Anouar Darif *
LRIT-GSCM Associated Unit to
CNRST (URAC 29), FSR
Mohammed V-Agdal University, BP
1014 Rabat Morocco
anouar.darif@gmail.com

Rachid Saadane
SIR2C2S/LASI-EHTP, Hassania
School of Public Labors Km 7 El
Jadida Road, B.P 8108 Casa-Oasis,
Casablanca Morocco
saadane@ehtp.ac.ma

Driss Aboutajdine
LRIT-GSCM Associated Unit to
CNRST (URAC 29), FSR
Mohammed V-Agdal University, BP
1014 Rabat Morocco
aboutaj@fsr.ac.ma

Abstract— **Wireless Sensor Network (WSN) have been attracting increasing interest for supporting a new generation of ubiquitous computing systems with great potential for many applications. However, the communication paradigms in WSNs differ from the ones associated to traditional wireless networks, triggering the need for efficient wireless communication technology. Several wireless technologies have emerged ranging from short and medium distance. Bluetooth, ZigBee and Impulse Radio Ultra Wide Band (IR-UWB) are three popular short range wireless communications. Due to its various features and advantages (especially low power consumption and low complexity), IR-UWB is a very promising wireless communication technology for WSN. In this paper, we evaluate the main features and advantages of this new technology (IR-UWB) for WSN in terms of transmission time, data coding and power consumption compared to Bluetooth and ZigBee. To analyze and evaluate the main features and advantages of IR-UWB as an efficient short range wireless communication technology for WSN, we used MiXiM platform under OMNet++ simulator.**

Keywords—WSN; IR-UWB; Bluetooth; Zigbee; Data Coding; Transmission Time; Energy Consumption.

I. INTRODUCTION

A WSN is a network consisting of numerous sensor nodes with sensing, wireless communications and computing capabilities [1]. These sensor nodes are scattered in an unattended environment (i.e. sensing field) to sense the physical world. The sensed data can be collected by a few sink nodes which have accesses to infrastructured networks like the Internet. Finally, an end user can remotely fetch the sensed data by accessing infrastructured networks. WSN consists of spatially distributed sensor nodes, each sensor node is able to independently perform some processing and sensing tasks. Furthermore, sensor nodes communicate with each other in order to forward their sensed information to a central processing unit or conduct some local coordination such as data fusion.

WSNs are intended to monitor events and phenomena in a specified environment [2] such as physical world, a biological system [3], or an information technology framework using autonomous [4] collection of sensor nodes with limited energy, storage and processing capabilities.

Generally sensors are deployed in large quantities with high density. So congestion is a likely event. Controlling congestion is difficult due to dynamically time varying wireless channel condition and contention caused due to interference by concurrence transmission and also traffic pattern in WSN is entirely different from traditional networks. In traditional networks destinations are random hence avoiding congestion is easy but WSN deliver myriad types of traffic ,its density increases when sudden event occurs and some nodes may worn out their battery power removal of such nodes in the network make uncongested part of the network become easily congested. This will degrade the network quality, increase the loss rate and unfairness toward nodes whose data has to traverse a large number of hops.

Various wireless communication technologies, like simple Bluetooth, Zigbee or IR-UWB might be used for communication between sensors nodes in WSN. In recent years, IR-UWB technology has drawn great interest in the wireless community [5]. The development of IR-UWB has ushered in a new era in short range wireless communications. Among various potential applications, one of the most promising is in WSN [6], which requires both robust communications and low power consumption capabilities. In this work we show the gain and good impact brought by using this new technology in WSN.

The present paper is organized as follows. In Section II we present Bluetooth and Zigbee. Section III presents a detailed of IR-UWB. The transmission time and data coding efficiency are presented in Section IV. Energy consumption is presented in Section V; finally, Section VI concludes the paper.

II. BLUETOOTH AND ZIGBEE

A. Bluetooth

Bluetooth technology is a short range wireless specification aimed at simplifying communications for Wireless sensor Networks (WSN), and it is a Radio Frequency (RF)

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specification for point-to-point and point-to-multi-point voice and data transfer. Starting from a headset cable replacement it has been extended to support flexible ad-hoc networks. To extend from low bit rate data to streaming multimedia, Quality of Service (QoS) is required. Bluetooth specification defines strong interoperability demands between all Bluetooth devices. The interoperability requirements demand a lot from application developers. For making the developers' work easier it has been produced different Bluetooth development platforms. These development platforms have different purposes and capabilities [7]. The purpose of this thesis was to demonstrate and study Bluetooth technology and Bluetooth application development. The study consists of development platforms with Bluetooth hardware, Bluetooth protocol stacks, and applications on top of protocol stacks. The Bluetooth core specification contains both hardware and a software description.

Figure 1 depicts the Bluetooth protocol stack [8], which also shows the application and profiles "layer" for completeness. The Radio layer defines the requirements for a Bluetooth transceiver operating in the 2.5 GH. In order to make different hardware implementations compatible, Bluetooth devices use the Host Controller Interface (HCI) as a common interface between the Bluetooth host and the Bluetooth core. Higher-level protocols like the Service Discovery Protocol (SDP), RFCOMM (emulating a serial port connection) and the Telephony Control Protocol (TCS) are interfaced to base-band services via the Logical Link Control and Adaptation Protocol. Among the issues L2CAP takes care of, is segmentation and reassembly to allow larger data packets to be carried over a Bluetooth baseband connection. The Service Discovery Protocol allows applications to find out about available services and their characteristics when, e.g. devices are moved or switched off.

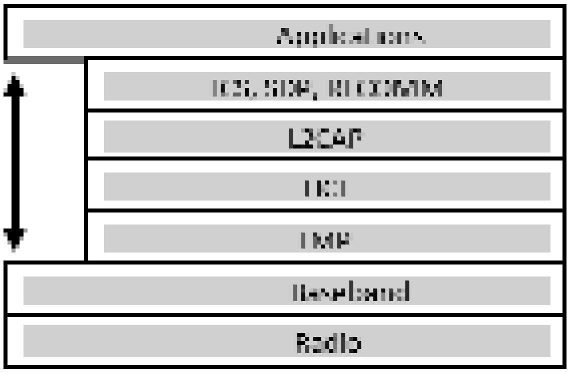

Figure 1. The Bluetooth Protocol Stack

Service Discovery Protocol (SDP), in specific, allows the users with Bluetooth devices to connect to the neighboring devices in a wireless manner. One notable characteristic about the SDP about the Service Discovery Protocol is its capability to enable Bluetooth wireless device users to get on-demand services. On July, 2000, the Bluetooth Special Interest Group (SIG) defined a process that enables system developers to employ the Salutation architecture for service discovery a utilization functions in Bluetooth short-range radio frequency (RF) networks. Further, SIG is developing new Bluetooth requirements, including Salutation and universal plug and play, to describe how to use other service discovery technologies in the Bluetooth environment. It is the authors' belief that service discovery architecture eventually will come into prominence with the popularity of mobile commerce technology.

B. Zigbee

Zigbee [9], defines specifications for low rate WPAN (LR-WPAN) for supporting simple devices that consume minimal power and typically operate in the personal operating space (POS) of 10m. It defines also two modes of operation: beacon enabled and non beacon enabled. In the former, a coordinator, called the Piconet Coordinator (PNC) sends periodic beacons. Beacons are followed by a so-called Contention Access Period (CAP), during which all nodes can compete independently for channel access using a CSMA/CA algorithm, and by a Collision Free Period (CFP), during which nodes communicate during time slots exclusively allocated by the PNC. In the non beacon enabled mode, nodes use a CSMA/CA protocol in their communication. ZigBee Alliance [10] defined the protocol stack upper layers.

In Zigbee network generally we can define three types of nodes [11][12]. These nodes are:

PAN coordinator: There can be only one coordinator for each ZigBee network. This node is liable for initializing the network, selecting the suitable channel and allowing other devices to connect to its network.

Full Function Devise: It can serve as the coordinator of a personal area network just as it may function as a common node. It implements a general model of communication which allows it to talk to any other device.

***Reduced Function Devise*:** These nodes are only used to talk either a router or a coordinator. An end device connected to the network through either a router, or directly to the coordinator. There are three different types of topologies possible for a ZigBee network.

The introduction of IR-UWB made this protocol unable to operate, since it relies on CCA (in both of its modes). Therefore, adaptations were defined in the standard. In particular, the CSMA/CA mode is replaced by an ALOHA mode that does not rely on CCA. The MAC sub-layer handles all access to the physical radio channel. It provides an interface between the service specific convergence sub-layer (SSCS) and the PHY layer.

III. IR-UWB

A. Presentation

IR-UWB technology as a next generation of the IEEE802.15.4 standard is a promising technology to address Wireless Sensor

Network constraints. However, existing network simulation tools do not provide a complete WSN simulation architecture, with the IR-UWB specificities at the Physical (PHY) and the Medium Access Control (MAC) layers.

The IR-UWB signal uses pulses baseband a very short period of time of the order of a few hundred picoseconds. These signals have a frequency response of nearly zero hertz to several GHz. According to [13] there is no standardization, the waveform is not limited, but its features are limited by the FCC mask. There are different modulation schemes baseband for IR-UWB [14]. This paper uses the PPM technique for IR-UWB receiver.

B. IR-UWB signal information

IR-UWB signals are transmitted in form of very short pulses with low duty cycle [15]. The signal transmitted by using Pulse position modulation can be represented as follows at the transmitter:

$$S(t) = \sqrt{E}\sum_{j} P_0(t - jT_{sym} - \theta_j - b_j T_{sym}/2)$$

Where:

E is the pulse energy,

$P_0(t)$ is the normalized pulse waveform

T_{sym} is the symbol duration

θ_j is the time-hopping shift for the considered symbol j

b_j is the jth bit value

$T_{sym}/2$ is the time shift for the modulation.

We Considering an AWGN channel of impulse response:

$$h(t) = \lambda\delta(t - \tau)$$

Where λ is the attenuation and τ is the delay.

The signal after propagation becomes (E_u is the energy at the receiver):

$$r_u(t) = \sqrt{E_u}\sum_{j} P_0(t - jT_{sym} - \theta_j - b_j T_{sym}/2 - \tau)$$

The received signal can be separated into three components:

$r_u(t)$: is the transmitted signal from the source transformed by the channel.

$r_{mai}(t)$: is the multiple access interference caused by simultaneous transmissions .

n(t): is the thermal noise.

The thermal noise is a zero-mean Gaussian random variable of standard deviation N$_0$/2 (where N$_0$ is the thermal noise given by $N_0 = K_B T$, K_B being the Boltzmann constant and T the absolute temperature).

The multiple access interference [16] can be expressed as follows:

$$r_{mai}(t) = \sum_{n=1}^{N_i}\sqrt{E^{(n)}}\sum_{j} P_0\left(t - jT_{sym} - \theta_j^{(n)} - \frac{b_j^{(n)}T_{sym}}{2} - \tau^{(n)}\right)$$

Where:

N$_i$ is the number of interfering signals,

$E^{(n)}$ is the received energy,

$\tau^{(n)}$ is the channel delay for the considered signal,

$\theta_j^{(n)}$ is the time-hopping shift ,

$b_j^{(n)}$ is the bit value for the jth symbol of the considered interfering signal.

The correlating received signal $S_{Rx}(t)$ with a correlation mask m(t) effect can be expressed as:

$$Z(x) = \int_{\tau}^{\tau+T_s} S_{Rx}(t)m_x(t-\tau)dt = Z_u + Z_{mai} + Z_n$$

With:

$$m_x(t) = P_0(t - xT_s - \theta_j) - P_0(t - xT_s - \theta_j - T_s/2)$$

The signal contribution (Z$_u$), the thermal noise contribution (Z$_n$) and multiple access interference (Z$_{mai}$) are the decision variable Z(x) component.

With Z$_n$ is Gaussian distributed with zero mean and variance:

$$\sigma_n^2 = N_0(1 - R_0(\varepsilon))$$

With:

$$R_0(t) = P_0(\varepsilon)P_0(\varepsilon - t)d\varepsilon$$

Considering Z$_{mai}$ is Gaussian distributed with zero mean and variance:

$$\sigma_{mai}^2 = \tfrac{1}{T_s}\sigma_M^2\sum_{n=1}^{N_i} E^{(n)}$$

With:

$$\sigma_M^2 = \int_{-\infty}^{+\infty}\left(\int_{-\infty}^{+\infty} P_0(t-\tau)(P_0(t) - P_0(t-\varepsilon))dt\right)^2 d\tau$$

C. The Frame Format

In IEEE 802.15.4a IR-UWB PHY layer networks, devices communicate using the packet format illustrated in Figure 2. It consists of three components: synchronization preamble (SP), PHY-header (PHR), and payload. The very short duration of the pulses makes them difficult to detect. Since there is no carrier signal, the channel is empty most of the time even though a transmission is ongoing. The only part of the signal that can be reliably detected (using a dedicated algorithm) is the synchronization preamble, with which all transmissions begin. It consists of a deterministic sequence of isolated pulses used by all devices that are part of the same network (two synchronization preambles are defined in the standard).

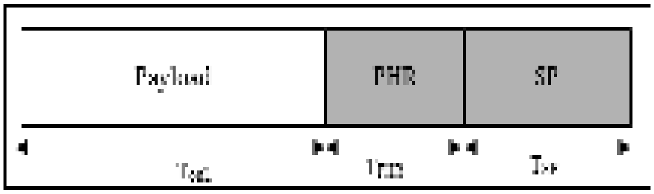

Figure 2. The IEEE 802.15.4A IR-UWB PHY Frame.

D. Radio State Machine

Since the power consumption is derived from the time spent in each of the radio modes, it is important to model these accurately. The finite state machine illustrated in Figure 3 is used, with three steady states *Sleep*, *Rx* and *Tx*, and four transient states *SetupRx*, *SetupTx*, *SwitchRxTx* and *SwitchTxRx*. The radio can always leave any state (steady or transient) and immediately enter sleep mode.

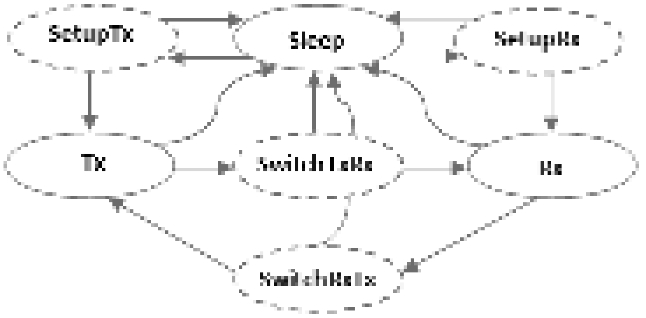

Figure 3. Detailed radio model including transient states.

E. IR-UWB Advantages

There are several features of IR-UWB signals which make them attractive for a wide range of wireless applications [17]. Some of the major advantages of IR-UWB are, low complexity, low power consumption, and good time-domain resolution allowing for location and tracking applications. With all these advantages, the IR UWB approach has been selected "in providing communications and high precision ranging/location capability (1 meter accuracy and better), high aggregate throughput, and ultra low power; as well as adding scalability to higher data rates, longer range, and lower power consumption and cost"[18].

IV. TRANSMISSION TIME AND DATA CODING EFFICIENCY

A. Transmission Time

The transmission time depends on the data rate, the message size, and the distance between two nodes. The formula for transmission time (µs) can be described as [19]:

$$T_{tx} = \left(N_{data} + \left(\frac{N_{data}}{N_{maxpld}} \times N_{ovhd} \right) \right) \times T_{bit} + T_{prop}$$

where N_{data} is the data size, N_{maxpld} is the maximum payload size, N_{ovhd} is the overhead size, T_{bit} is the bit time, and T_{prop} is the propagation time between any two devices. For simplicity, the propagation time is negligible in this paper. The typical parameters of the three technologies used for transmission time evaluation are listed in Table I.

To ensure an acceptable quality of service of any wireless communication technology, we were obliged to study the transmission time. As shown in Figure 4, the transmission time for the ZigBee is longer than the others because of the lower data rate, while IR-UWB requires less transmission time compared with the others. Obviously, the result also shows the required transmission time is proportional to the data payload size.

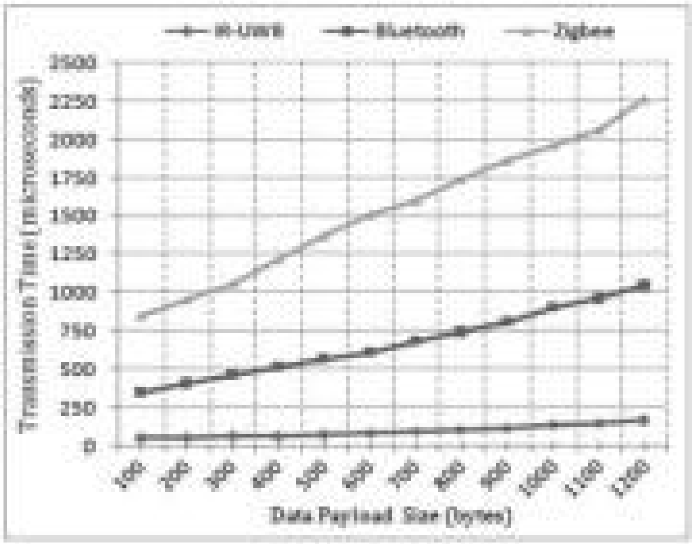

Figure 4. Transmission time versus the Data Payload size.

TABLE I. TYPICAL SYSTEM PARAMETERS

	Bluetooth	***ZigBee***	***IR-UWB***
Max data rate(Mbit/s)	0.72	0.25	2
Bit time (µs)	1.39	4	0.009
Max data payload (bytes)	339	102	1020
Max overhead (bytes)	158/8	31	42
Coding efficiency (%)	92,13	74,42	97,94

B. Data Coding Efficiency

The data coding efficiency is defined by the ratio of the data size and the message size (i.e. the total number of bytes used to transmit the data). The formula for data coding efficiency (%) can be described as:

$$P_{codEff} = N_{data} / (\mathrm{N_{data}} + (\mathrm{N_{data}} / \mathrm{N_{maxPld}} \times \mathrm{N_{ovhd}}))$$

We used the parameters listed in Table I for the coding efficiency comparison. Figure 5 shows the data coding efficiency of the three wireless networks versus the data size. For small data sizes (around smaller than 400 bytes), Bluetooth and IR-UWB are the best solution. Also, ZigBee have a good efficiency for data size smaller than 200 bytes. For large data sizes, IR-UWB has much better efficiency of over 97%, as compared to the 74.42% of ZigBee and 92.13% of Bluetooth. For a wireless sensor network in factory automation systems, since most data size of industrial monitoring and control are generally small, (e.g. the temperature data in an environmental monitoring may required less than 4 bytes only), Bluetooth may be a good selection (from a data coding efficiency point of view) in spite of their slow data rate. But it consumes more energy compared with IR-UWB for this reason it is preferable to use IR-UWB.

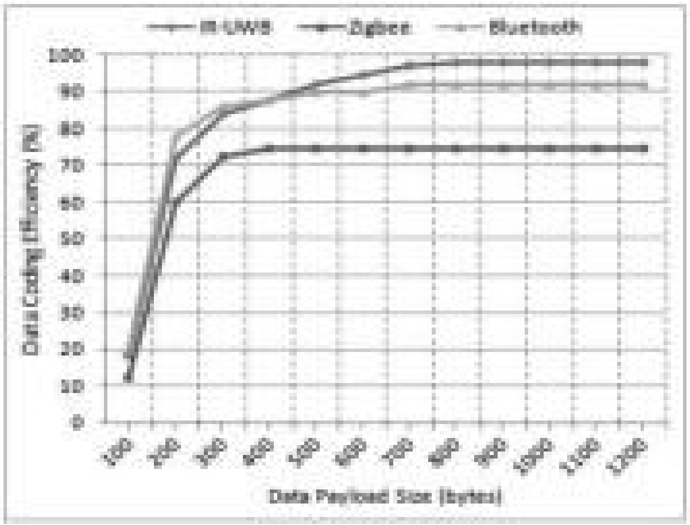

Figure 5. Data coding efficiency versus the data payload size.

V. ENERGY CONSUMPTION

The total of energy consumed in unit time includes the energy spent in transmission (noted: E_{tx}) and reception (noted: E_{rx}) of data packets, in transmission and reception of control packets (noted: $E_{overhead}$), in listening to the channel (noted: E_{idle}) and in reception of neighbors' packets (noted: $E_{overhearing}$) [20].

$$E_{Consumed} = E_{tx} + E_{rx} + E_{Over\,head} + E_{idle} + E_{Over\,hearing}$$

Since each sensor node can generate its own traffic and forward traffic of other nodes, the energy spent by a node N_i in packet transmission in time interval [0, t] can be computed as the sum of the amount of energy consumed in sending its own traffic, in forwarding traffic of other nodes and in sending acknowledgements related to received packets to be forwarded:

$$E_{tx_i}(t) = t.P_{tx}\left(\left(TtransPkt.(g_i + f_i)\right) + (TtransAck.f_i)\right)$$

where P_{tx} is the power consumption in transmitting one packet, $T_{transPkt}$ is the transmission time of a data packet, $T_{transAck}$ is the transmission time of an acknowledgement, g_i is the packet generation rate (packet/second) for a node Ni and f_i is the packet forwarding rate (packet/second) by a node Ni. Similarly, the energy spent by a node Ni in packet reception in time interval [0, t] can be expressed as follows:

$$E_{rx_i}(t) = t.P_{rx}\left((TtransPkt.f_i) + \left(TtransAck.(g_i + f_i)\right)\right)$$

where P_{rx} is the power consumption in receiving one packet, $T_{transPkt}$ is the transmission time of a data packet, $T_{transAck}$ is the transmission time of an acknowledgement, g_i is the packet generation rate (packet/second) for a node Ni and f_i is the packet forwarding rate (packet/second) by a node Ni.

Reducing the energy consumption of wireless communication systems is mainly achieved by duty-cycling the radio and keeping it in sleep mode as much as possible. IR-UWB is the good candidate for this reason as shown in Section III.D. Energy consumption was and is an interesting issue that is still a factor in the development of WSN. This factor affect directly the lifetime of the network.

The low power consumption of the nodes network based on IR-UWB was concretized by the results shown in Figure 6 and Figure 7, varying respectively the data payload size and the nodes' number. They show that the power consumption by the WSN nodes based on IR-UWB is remarkably less than the case of Bluetooth and Zigbee. Figure 6 shows clearly that the value of power consumption increase with increasing the data payload size due to the required power for sending all data packet. The result shown in figure 7 is obtained by a data payload fixed at 512 bytes and varying the nodes' number. It shows also the linear dependence between the power consumption and the nodes' number.

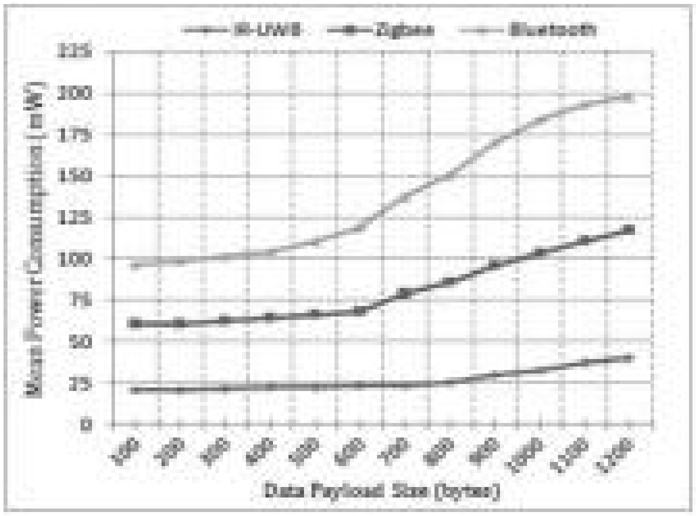

Figure 6. Nodes' power consumption average versus data payload size.

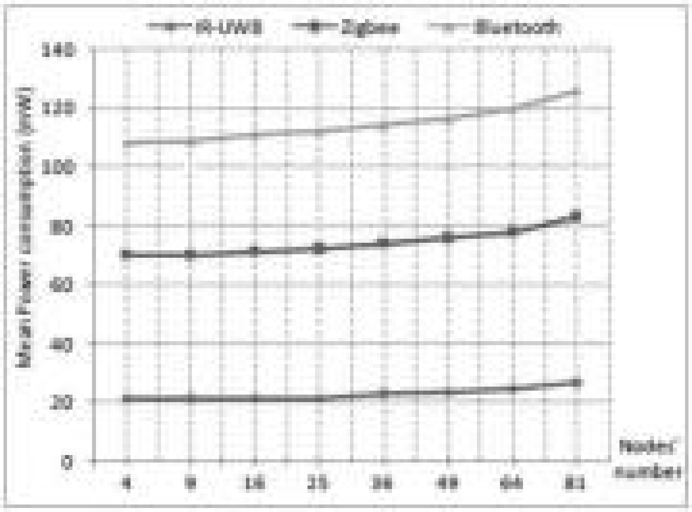

Figure 7. Nodes' power consumption average versus nodes number.

VI. CONCLUSION

To improve the performance of Wireless Sensor Network we need an efficient Wireless communication technology. IR-UWB was mainly introduced in the field of WSN due to its various specificities and advantages, especially its low power consumption, robust communications and low complexity advantages. In this work we evaluate the efficiency of IR-UWB in terms of transmission time, data coding and energy consumption compared to Bluetooth and Zigbee. The good results in the case of the WSN based on IR-UWB are obtained due to the features and advantages of this new technology listed above. As a future work, we aim to improve the QoS in the MAC layer by developing a new adapted Medium Access Control (MAC) protocol that will be paired with this new technology.

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