Presentation and analysis of a new technology for low-power wireless sensor network

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ABSTRACT

The tremendous and rapid development in sensors technology allowed their application in various fields requiring monitoring, such as, transportations, rare species surveillance, agriculture, military activities, medical field, etc. Due to their intrinsic constraints and limitations, several dedicated MAC protocols have been designed for wireless sensor networks and whose main objectives are bandwidth optimization while keeping very low energy consumption. One of the newest proposals is ANT which is emerging as a widely used MAC protocol for wellness and sports sensor devices.
In this paper, we give a comprehensive overview of ANT/ANT+ and a comparison between ANT and two established standards: Bluetooth Low Energy (BLE) and 802.15.4/4a. We detail also some practical experiments we conducted to evaluate some characteristics of ANT.

KEYWORDS

ANT, 802.15.4, BLE, WSN, MAC protocol.

1 INTRODUCTION

Wireless Sensor Networks (WSNs) have been proposed for many applications requiring the collection and aggregation of environmental data detected in a certain area of perception. We can mention some typical applications: the monitoring of vehicle movements in hostile area [1], the observation of the lives of rare species [2], the monitoring of the structure of infrastructure [3] [4], medical assistance [5], etc. Several researches are directed to design new MAC protocols adapted to the characteristics of wireless sensor networks. To this end, several MAC protocols [6] [7] [8] [9] have been proposed in the literature to optimize access to the wireless medium. In recent years, we have witnessed a major expansion of the ANT (Advanced and adaptive Network Technology) [10] protocol and its extension ANT+. These protocols are considered by the industrial community as a well suited architecture to the monitoring applications in sports and medical domains, where it is necessary to use wireless sensor networks.

ANT is a communication protocol with ultra low power consumption. It maximizes battery lifetime and provides the use of many channels. It has a very good theoretical baud rate which attends 1Mbps, making this protocol more suitable for Wireless Personal Area

Networks with low bandwidth (LR-WPAN).

ANT+ adds network management layers which enables interoperability, defines data structure, provides definition of node profile and manages network keys.

In this paper, we propose to present a theoretical overview of ANT and ANT+ and some practical tests conducted with real material.
This paper is organized as follows: In the beginning, we present the basic principles of ANT protocol and ANT+. Then, we present a comparison between ANT, BLE [24] [25] [26] [27] [28] and 802.15.4/4a. Next, we present a practical study of ANT. In the end, a conclusion comes to take stock of our study and discusses the prospects for research on which we move.

2 PRESENTATION OF ANT

ANT is a protocol designed for wireless personal area networks (WPAN) with low power consumption, low processing power and low baud rate. The small size of the ANT protocol stacks allows the integration into components such as: PDAs, watches, phones, Smartphone, etc. It operates in the 2.4GHz ISM (Industrial, Scientific and Medical radio bands) band and allows for a flow baud rate of 1Mbps with transmission duration less or equal than to 150 microseconds / frame for 8bytes of data.

ANT provides a management of Physical, Data link, Network and Transport OSI layers (Fig 1). It's a very compact stack requiring minim material resources.

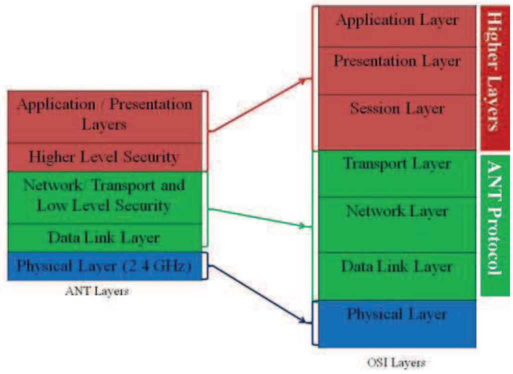

Figure 1. Correspondence between the ANT model and the OSI model

2.1 ANT Node

ANT defines two types of nodes. The first type is the master node. It is the initiator of communication, the responsible of controlling the channels and the transmitter of data (the primary transmitter). Its window of reception is used to provide the co-existence of many masters in the same network with the same frequency and to receive data from slaves or other masters (Figure 2).

The slave node, the second type of node, is the primary receiver of a frame from the Master and responsible of synchronization with the master (Figure 2 (a)).

In ANT protocol, a node can act as a master and a slave at the same time with different nodes. In Figure 2 (b), we have three nodes where the node 1 is a master of node 2 (slave in this case) and the node 2 is the master of the node 3 (slave).

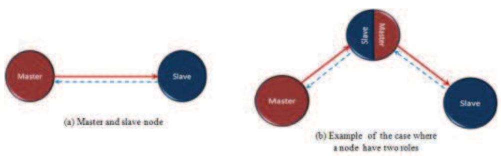

Figure 2. Different roles of a node

2.2 ANT channels

2.2.1 Parameters

The ANT protocol uses 2.4 GHz bandwidth and divides it into 125 channels of width equal to 1 MHz and a baud rate of up to 1 Mbps.
In order to create a connection between two nodes, they must have the same channel configuration. Then the slave needs to know several parameters we cite here after [21].

a- Network

ANT can set up several private and public networks. In order to establish a communication between two nodes, they must be in the same network, which enables a network service that can be shared with multiple source nodes. On the other hand, we can establish a private network to ensure confidentiality and restrict access. ANT node can participate in several networks since the channels can be assigned independently to multiple networks. This parameter contains two information: Network number and Network key.

Network number is coded on 8 bits and varies between 0 and a maximum value fixed during the implementation of ANT. The default value of the network number is 0.

The Network Key is coded on 8 bits and configured by the application. Each network must have a network key. The key and the network number allow the deployment of networks with a varying level of security and access control. Initially, the default network number is equal to 0 with a public network key and no rule for the use of the network.

b- Frequency RF (Radio Frequency)

It represents the frequency where the network operates. For example, if Frequency RF is equal to 66, then the network is operating at 2466 MHz.

In ANT protocol a channel must operate on a single frequency among the existing. The RF frequency is coded on 8 bits and varies between 0 and 124.

The Frequency RF value represents the offset from the 2.4 GHz by 1 MHz increment.

c- Channel ID

This is the most important information for the channel. The higher layers are responsible for the specification of this parameter. The value of Channel ID is coded on 4 bytes and contains the following information:

- Transmission type: 8 bits, it presents the type of transmission
- Device Type: 8 bits, this field is used to differentiate between different types of nodes in the network, which allows participating nodes to know the different classes of connected nodes, and hence they can decode the information received. If the device type is equal to 0, the receiving node can connect to multiple types of nodes.
- Device Number: 16 bits, supposed to be unique in the network.

Table 1. Transmission types and characteristics

	Forward direction	Reverse direction
Broadcast	-Send the data in each time period. -The data are not acknowledged. -If the higher layer does not send new data, ANT retransmits the last data received by the HC layer. -The frames are sent only once.	-Send at the end of the period of transmission of the master. -Frames sent by this type of communication are never acknowledged.
Acknowledged	-The master may decide to send a frame with the request of acknowledgement during the step of establishing a two-way connection. -The HC layer can choose to send all data frames with a request of acknowledgement or it mixes the broadcast transmission and data transmission with acknowledgment. -Communication by request of acknowledgment of data uses more bandwidth and consumes more energy. -This type of transmission is important for critical data. -There is no automatic retransmission of data packets without acknowledgment. -If the ANT protocol doesn't have a new data in the interval time, the last frame is retransmitted.	-The slave may send a frame to be acknowledged by the master at the end of the master transmission period during the stage of establishing a two way connection. -There is no automatic retransmission of data packets without acknowledgment.
Burst	-This mechanism is used by the master to transmit a large amount of data to the slave. -The burst transmission begins in the transmission period and it is expected to send a set of frames that must be acknowledged by the slave. -All lost frames are automatically retransmitted. -The transmission time is not limited - Data rate is up to 20kbps. -The channel that uses this type of transmission has priority over all other channels	Data can be sent to the master by the burst transmission in the same manner described in the master.

d- Channel type

This parameter defines the type of transmission that will occur in the channel. It is coded on 8 bits and can define eight types of communication.

e- Channel period

This is the basic frequency used by the master for transmission of data. By default, this parameter represents the interval time between two successive transmissions of data transmission with broadcast transmission (Figure 3). The frequency of data frames in a channel varies between 0.5Hz and 200Hz and the default frequency is equal to 4Hz. The channel period is coded on 16 bits.

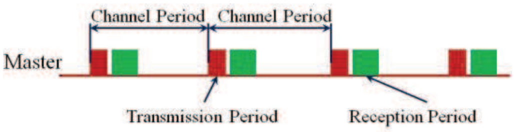

Figure 3. Channel transmission

f- Data Type and format

The data type field determines the type of communication taking place between the participants of this channel and it is fixed by the higher layers. Communication consists generally of two levels [21] (Table 1):

- Manage the direction (Figure 4)
  - Forward direction (from the master to the slave)
  - Reverse direction (from the slave to the master)
- Specification of type of communication
  - Broadcast
  - Acknowledge
  - Burst

ANT does not provide an algorithm to ensure the QoS in the network, but it defines only the acknowledgement packet. This packet must be transmitted by the slave node when it receives a frame that requires an acknowledgement. This ACK is used only to inform the master that the frame was transmitted successfully. ANT does not retransmit the unacknowledged frame.

2.2.2 Different methods of channels management

ANT defines three different ways to use the channel: Independent channels, Shared channels and Channels scan.

In the independent channels, the channel has one master and one slave. The node can have a different role in another channel. The node can support a limited number of independent channels.

The shared and scan channels are used when an ANT node must receive data from multiple sources.

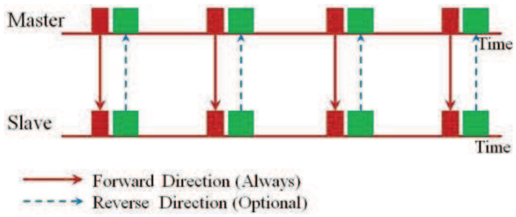

Figure 4. Channel communication direction

In the channel scan mode, the slave node is on receiving state all the time, for this reason it can receive the data from multiple masters at any time. The radio is always in the continuous scan mode, so the ANT node cannot open other channels.

2.2.3 Establishment of a channel

If two nodes want to communicate, they must undergo the following process: First, the master sets the type of network, the frequency, the message rate and the channel ID. Secondly, it establishes the channel by transmitting the channel ID with the data in a particular time interval (channel period). ANT channel will be maintained indefinitely at the given time interval and frame baud rate. The higher layers of the master will eventually provide new data to the ANT protocol for continuous transmission. Thirdly, the slave opens its channel to search for a specific master or to search a subset of masters (the type of research depending on the configuration of slave channel). When the slave receives the first message, it selects the type of network, operating frequency, and frame baud rate of the master. With this information it can synchronize with the master and begin receive data [11][21][17].

In ANT, after the synchronization step, in the ideal case, we don't have a transmission failure if the slave node is in the transmission ranges of the master nodes. If the slave node is connected to many master nodes, it switches between channels to receive the information.

2.3 Device pairing

Pairing action consists of establishing a relationship between two nodes that wish to communicate together (master and slave). This relationship may be permanent, semi-permanent or transitory.

It consists of a slave device acquiring the unique channel ID of the master device. In the case of a permanent pairing, the slave node must keep the identity of the master in the permanent or nonvolatile memory. This ID is used to open a channel with this ID in all subsequent communication sessions. In semi-permanent relationship, the pairing lasts as long as the channel is maintained [12][21].

3 PRESENTATION OF ANT+

ANT+ is an enhancement of ANT protocol by adding the interoperability function and defining the data structure, channel parameters and the network keys in order to enable the communication with others ANT+ products. A managed network, ANT+ simplifies the collect, transmission and tracking of health information.

ANT+ allows shared access to the channel; it manages the definitions of node profiles and adds it to the managed networks in order to know the needs of the participant nodes.

ANT+ is used in any application including wireless sensor monitoring in sport, wellness or home health such as: temperature sensor, heart rate monitor, speed and distance monitors, bicycle power, blood pressure, etc.

The Figure 5 presents the layers defined by ANT+. The use of ANT+ and ANT together offers an Ultra low power wireless technology solution and enables the interoperability between nodes (Figure 5).

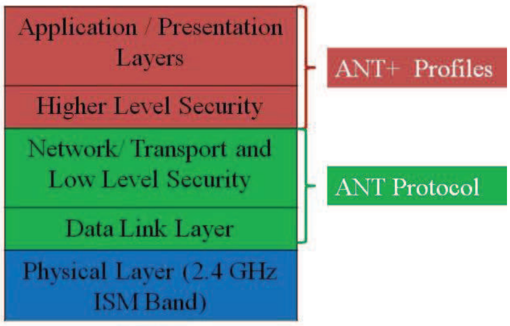

Figure 5. Layer model of ANT/ANT+[20]

4. COMPARISON BETWEEN ANT AND OTHER PROTOCOLS

Table 2 presents a comparison between 802.15.4/4a, Bluetooth Low Energy (BLE) and ANT protocol. We note that 802.15.4a have a transmission rate greater than that of ANT, BLE and 802.15.4. The range of transmission of 802.15.4/4a is greater than that of ANT and BLE.
The transmission range and rate of ANT and BLE are equal.

In 802.15.4/4a a node can be an FFD or RFD, the RFD nodes will be connected to an FFD node. In the other hand, an FFD node can be a coordinator or a router for other nodes and can be connected to all types of nodes in the network. In ANT we have two different nodes: a simple node (sensor) and a central node. Simple nodes collect the information and send it to the central node where it will be conserved.

BLE is not compatible with classical version of Bluetooth. But, a node can implement a dual mode to be able to communicate with BLE or classic Bluetooth nodes.

Finally, ANT can be used for transmission of data with small size. 802.15.4/4a can be used for the transmission of big size of data and it allows us to allocate time slots and use TDMA to transmit the data (generally used for QoS application).

5. PERFORMANCE STUDY

In this section, we will present some radio measurements of ANT protocol. Our goal is to understand how ANT transmits messages and uses the bandwidth and to verify if ANT offers the same theoretical baud rate with burst transmission rate. For this reason, we used two ANT USB keys and two spectrum analysers (WiSpy [22] and a classical HP tool) to observe the power on the physical wireless medium and the frequency of the signal transmitted by ANT USB. The WiSpy has a intersting functionnality for our performance study: it represents temporal medium energy density. This functionnality enables us to view medium activity, especialy in burst mode.

ANT USB is a computer dongle used to receive, store, analyze and display data transmitted by another ANT USB or other devices like ANT sensor and watch.

There are two ANT USB generations, USB1 and USB2. The first generation, USB 1, is replaced by the second generation and it is no longer used. The USB 1 and USB 2 have the same hardware. The difference between the two generations is in the software application only. Where, the new software offers better functionality and performance. In our tests, we used the second generation USB2.

Table 2. Comparison between ANT and 802.15.4/4a

	802.15.4	802.15.4a	ANT	BLE
Frequency band	3 frequency: 868, 915 and 2400MHz	3 frequency: Sub-Ghz, low band and high band	2400MHz	2400MHz
Channel numbers	27	- 16 with UWB - 14 with chirp signal	8 channels	40
Max Packet Play load (bytes)	100		8	20
Range (meters)	100		30	10m and other ranges depending on application
Min configuration	Transceiver		Transmit only or transceiver	Transceiver
Node Type	A node can be: FFD (Full Function Device) or RFD (Reduce Function Device)		We have two types of node: central node (for collecting the information from simple nodes) and simple node (transmit the detected information to the central node)	Single mode (BLE) or dual mode (Bluetooth & BLE)
Battery life	6 months		Up to 3 years	1 year
Synchronization	The transmission of beacon periodically		The transmission of the parameters of synchronization in all transmitted packets	By the master (AFH)
Mode of transmission	We have 2 modes: beacon enabled (where we use CSMA/CA for transmission without QoS and TDMA for the data that need a QoS and non beacon enabled (we use CSMA/CA only)		Best effort	advertising event & connection event

The USB2 stick is characterized by [13]:

- It uses the ISM band and uses the frequency from 2403 to 2480MHz,
- It supports the Broadcast, acknowledged, or burst data transmissions,
- Its minimum message rate per channel is 0.5 Hz,
- Its burst transfer rate is limited by 20kbps,
- It uses up to 8 channels,
- It has the scanning mode,
- It has up to 3 public, managed and/or private network keys.

These USB sticks will work in the 2466MHz frequency, the frequency of transmission is equal to 4 Hz.

We have configured the ANT USB to use the 2466MHz frequency to transmit data with a transmission frequency equal to 4 Hz, these values are the default values of the ANT product.

We have transmitted 1000Kbytes of data with burst transmission. Our goal is to test and verify the correct functionality of ANT protocol.

The Figures 6 and 7 will help us to find the center frequency and the spectrum large that are used by the node. The Figure 6 represents the signal transmitted by the ANT USB and detected by the oscilloscope. This spectrum is periodic and shows the effect of this transmission in the networks. The device uses the full bandwidth from 2464 to 2468MHz frequencies to transmit the data and we have a peak in 2466MHz, so ANT USB uses a bandwidth with 1 MHz of width and a center frequency equal to 2466MHz.

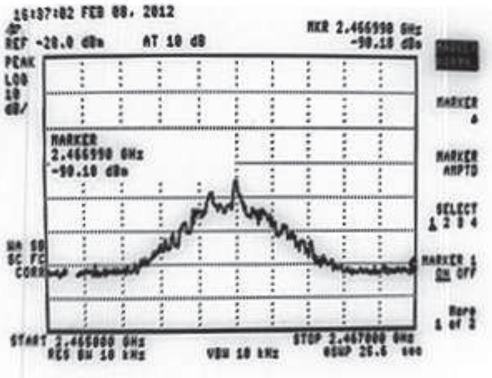

Figure 6. Spectrum analysis by the HP tool during the transmission of 1000Kbytes

In Figure 7, we note the existence of points with different colors. These colors represent the power level on every spectrum portion generated by the transmitter during the message's broadcast. As you note, the frames are sent on 2466MHz (center frequency) presented with red color and when the points are moving away from the center, the transmission power decreases. The variation of transmission power appears in Figure 7 by the change of the colors.

The transmission of data has taken some time. This delay made us deduce the baud rate and compare it with the theoretical value.

ANT protocol took 7min and 29seconds to transmit a payload of 1000Kbytes, which means it transmitted 20568bits per second. This result is the same presented in the theoretical study and USB sticks characteristic.

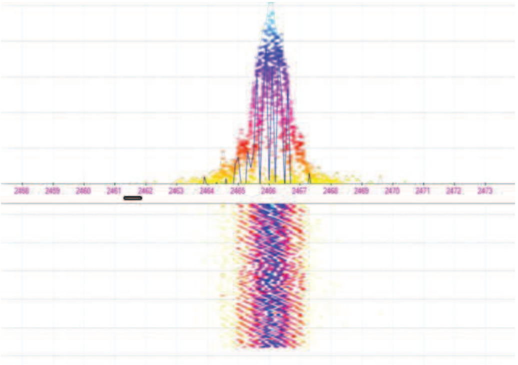

Figure 7. Spectrum analysis by the WiSpy during the transmission of 1000Kbytes

We have used a single channel and since ANT allows the use of multiple channels, we decided to test this property and look at the effect of the use of four channels which have the following frequencies:

- Channel 0: 2420MHz
- Channel 1: 2440MHz
- Channel 2: 2460MHz
- Channel 3: 2480MHz

We note in Figure 8 that the transmission is not performed on all channels, we only have signal in 2 channels (channel 0 and channel 3). Then we deduce that ANT can't transmit in many different channels at the same time. This is because the channel period is not very large and the time of transmission of one frame is equal to 150microseconds.

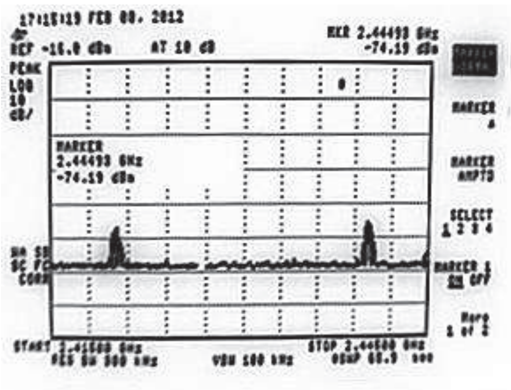

Figure 8. Result of the multi-channels tests

Now, we will test the possibility of transmission over 8 channels with the same frequency.

In Figure 9, we can see the effect of using 8 channels in the same time. The transmission is occurred between 2464 and 2468MHz and the center frequency is 2466MHz.

Hence, we can deduce that ANT allows the transmission over multiple channels in one condition: all channels will be configured to transmit at the same frequency as shown in Figure 9. We, also, note that the results shown by Figure 9 are close to that presented by Figure 7 but here we don't use burst transmission, we use broadcast transmission instead. In addition, in the Figure 7 we note that the transmission is occurs in different frequencies in the interval [2464MHz, 2468MHz]. This variation of frequencies permits to avoid the collision. The points represent the transmission and the reception periods.

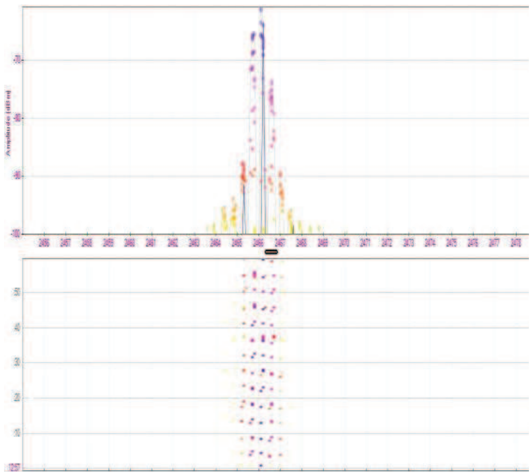

Figure 9. Result of the transmission in 8 channels in the same frequency

In this section, we have presented some practical test of ANT protocol realized with the use of two ANT USBs. When we use burst transmission ANT uses all the bandwidth and stops other transmission.

In the second test, we have many transmissions in the same bandwidth, despite we haven't interference. This is explained by the fact that ANT protocol allows a single channel to be divided into hundred of timeslots to ensure the co-existence of many transmission in the same frequency and the use of an adaptive isochronous network technology which provides the ability for each node to have a free time slot within the used bandwidth. Also, ANT protocol is used for the transmission of low data quantities, which limits its use to some monitoring applications only.

6. CONCLUSION

In this paper, we presented a new emerging protocol for wireless sensor networks which is at early stage of development and improvement. Yet, it is already widely used in sports and health monitoring field.

At first, we made a general presentation of the ANT protocol. Then, we presented the enhancement and the new functionality added by ANT+. Next we compared ANT with BLE and 802.15.4/4a, and we deduced that ANT can be used only for application where we don't have a large amount of data collected and do not require QoS. Finally, we presented some practical tests we conducted with real material, where we compared the theoretical study with real analysis of ANT protocol.
In our future work, we will perform more advanced testing with this protocol with an ANT Development Kit[23], so we can properly confirm the theoretical study of ANT and ANT+.

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