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Measurement of Power Consumption in Wireless Zigbee Network Nodes

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Abstract-The results of the implementation of a novel measurement technique in monitoring variations of power consumption in wireless sensors network nodes which operate under the ZigBee protocol are presented in this work. A simple wireless ZIGBEE network consisting of three nodes (one sample from each of the typical node types) is measured with the proposed energy measuring configuration. The measurements are performed during the switch-on or switch-off operation of the nodes and the resulting waveforms provide useful information about the energy consumption of each node type, in each phase operation or “handshaking”.

I. INTRODUCTION

The ZigBee protocol is based on the IEEE 802.15.4-2003 standard for wireless communication and focuses mainly to address the needs for very low cost, low consuming power, and low data rate networks such as the wireless sensor networks. ZigBee networks include two types of devices:, the Full Functioning Devices (FFD) and the Reduced Functioning Devices (RFD), which in turn are used as three different operational devices: the coordinator, the routers, and the end-devices. Routers can be used to extent the range of the network, allowing the other devices to connect to the network by sending (re-transmitting) their data packages through them. The ZigBee protocol is assuming continuous use of power supply and operation for both the routers and the coordinator, allowing only the end-devices to possibly operate on batteries by shifting to a low-power sleep-mode of operation. A specific set of specifications have been adopted for communicating between small size devices that usually implement non-intensive tasks, like making infrequent measurements, or controlling remote devices in an automated environment. The aim is low power implementations where the maximum possible extension of battery’s life is an essential specification.

ZIGBEE networks nodes have been designed to provide low-power solutions for low bit-rate wireless communications [1,2]. These devices are being explored in terms of energy, and attempts are made in order to improve them by making them less energy consuming [3-6]. Usually, the information which is available to designers about the energy consumption of different units is poor. In most of the situations, it is based on theoretical studies and on simulation tools. Also, the available information usually concerns simple tasks, like single instructions. If such a system becomes complicated, it will be difficult to be aware of its energy behavior during each phase of operation status.

The paper is presenting the results of engaging a novel measurement technique for the power supply current of any electronic configuration [3,4] to monitor energy consumption of a ZIGBEE unit (node) during the main operations in a wireless network. By monitoring accurately the power-supply-current of any electronic configuration during a certain operation one obtains valuable information about the energy consumption of the total configuration during the specific phase of operation (or alternatively the power consumption associated with this specific operation of the configuration. The proposed measuring scheme is able to measure the energy consumed by each of the ZIGBEE nodes during certain (well defined) time windows, that is during different operational procedures between the nodes of the wireless network.

II. THE MEASUREMENT APPROACH

In terms of power consumption a ZIGBEE network includes two types of devices: those that are “always on”, and those that may be “on” only when needed, minimizing thus the energy consumption during certain time-windows when they are in an idle operational status. As mentioned above the ZIGBEE network devices are separated into three categories. The first type is the coordinators, which are the center-device of a network and all other devices are exchanging data with them. The second type of devices are the routers, which connect to an already existent network (a coordinator), but also accept connections from other devices to the coordinator through them, that is they offer also a short of re-transmitting service to the network. The third type of devices is called end-devices: they are supposed to perform the basic operation (or service) of the network (i.e. measure certain parameters). Consequently their only way of data communication is to exchange data with one of the two previous types of devices (either directly to a coordinator, or to a router who re-transmits the information to another router or to the coordinator, etc). These devices are not required to operate fully the whole time, since their operational mode is configured independently (for each one), and they do not provide any type of communication service to other nodes. Unlike the other two types, they may be switched “off” during time intervals when no operation is required from them, offering thus a low-power mode of operation.

ZIGBEE is protocol for low-rate wireless networks, offered by many different companies who construct microelectronic devices. Implementations of ZIGBEE are based on a main processing unit, usually a microcontroller, along with an RF transceiver. The protocol of ZIGBEE is implemented in the firmware program of the microcontroller which certainly may be different for each company. Nevertheless, all of them have adopted the appropriate specifications in order for devices from different companies to be able to communicate to each other. Since the implementation is based on similar but not same programming, it is expected for these devices to behave differently as far as their energy consumption is concerned, yet this is not the primary goal for this investigation. The present work is focused on illustrating the variations of power consumption during the different phases of operations of a simple three nodes network: a coordinator, a router and an end-device. The hardware used is a development board from Texas Instruments (ez430-RF2480) which includes an RF transceiver (cc2480) with the ZIGBEE stack already loaded in the unit, along with a general purpose microcontroller (msp430F2274) for supervising the transceiver unit. So, this paper is focused on how Texas Instruments’ stack is implemented in terms of power consumption of each phase of operation. The exact operation of the transceiver is achieved by the commands that can be passed to the transceiver through SPI communication port of the microcontroller, while the stack itself is not accessible to the developer.

The power-supply current measurement technique is shown in Fig.1. The instantaneous current measurements are easily converted to energy consumption measurements since the power supply voltage is constant. This specific configuration has been already tested by the same group for similar type of measurements in other digital or mixed-signal systems [3,4].

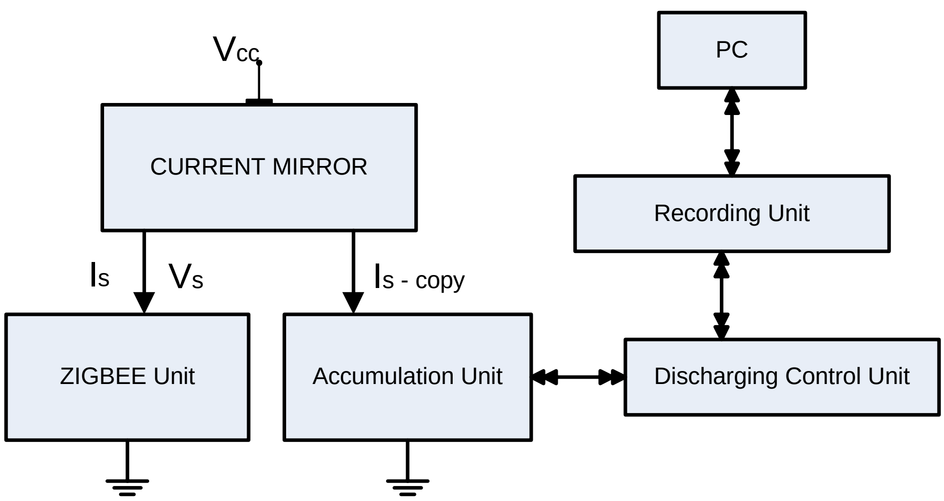

Fig.1. Measuring Configuration

This approach has been developed for monitoring and recording the current that a system draws by its power supply. The input branch of a current mirror is the power-supply-current (I_s), drawn by the system under test (the ZIGBEE unit) in our case. This ZIGBEE unit is one of the three units (coordinator, router, end-device) of our small network as mentioned earlier. The output current (exact instantaneous copy of the I_s) is fed to a summing unit (accumulation unit) which is actually a pair of capacitors. These capacitors, along with the rest of the circuit, are continuously summing this duplicated current of the current mirror. Each of the capacitors is charged and when is considered fully charged, a proper control circuit switches the current to the other capacitor and discharges the first one. The recording unit is counting how many discharging operations took place within a specific time window (e.g. the time window that takes for a routine to execute). The rate of discharges is an exact indication of the current drawn (or of the energy consumed) by the unit under test. A relation between the input current and the measured number of events (discharges) may be formed [3,4], so this circuit can be used for measuring accurately average current values for a specified time-window of one charging phase of each capacitor. The number of these discharges is an exact indication of the current drawn (or energy consumed) during a well defined time-window corresponding to one measurement.

III. MEASUREMENT RESULTS

The case study for our hardware measurements concerning the energy consumption of the chosen ZIGBEE units is the one offered by Texas Instruments (mentioned above), with at least two units operating each time, a transmitter and a receiver. A similar study, based on an entirely different measuring technique, can be found in an innovative applications note [6]. An initial analysis based on the same technique has been presented in [8]. The coordinator is responsible for creating the network and the router or the end-device is connected to the router. There are some common steps to both units: The same device may be operated in all possible roles within a ZIGBEE network by appropriate configuration for each situation. The monitoring of the energy consumption is illustrating all phases of starting each unit when initializations occur, and continue with monitoring the phase of joining the network (handshaking). All units are being sent new configuration details and the stack is being restarted on both sides. From this point the devices are taking separate roles. As a next step, the coordinator waits for a device to connect, while the router or the end-device searches for a network to join. Once a network is formed, the devices bind to each other. If all the above steps end successfully, the final operation is the continuous transmissions for the router or the end-device, and the continuous receptions of the coordinator.

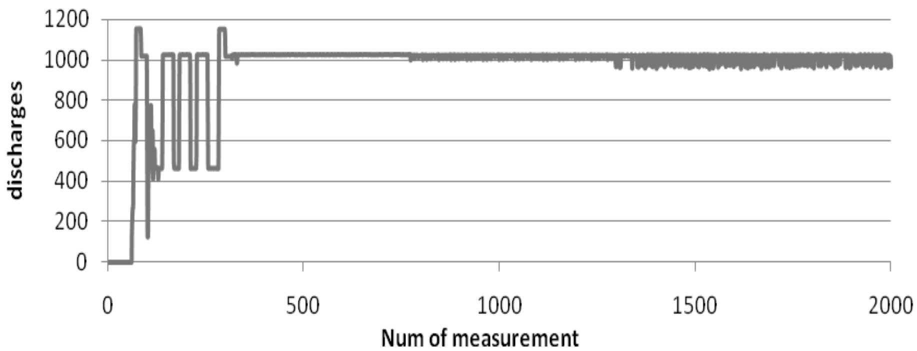

Fig.2. Typical measurements of power consumption on a router node

Curve of Fig.2 shows the results of a typical measurement on a router node of the ZIGBEE network. It contains 2000 measurements, while each measurement is performed at a time delay of 17,78ms after the previous one. This value is the result if using certain capacitance value (the same for both capacitors) and a certain “fully charged” voltage threshold). The number shown on the y-axis is the number of discharges that occurred and have been recorded by the measuring system. Thus the larger this number is, the more energy was consumed within the specific single-measurement window. This number can be converted accurately to current [3]. These measuring numbers are left as they are recorded in this presentation, so that the measuring procedure becomes more obvious. The measuring time window is not synchronized with any running operating on the router. So, the measured value is not associated to any specific part of the software code. By taking a closer look at this figure (Fig.2) one may correlate parts of this curve to operations being executed on the router. One may see the “power-on phase” of the system, during which the cc2480 is being reset. The significant variations which appear at the end of this phase are related to the joining procedure of the router to the coordinator’s network (“handshake”) and to the final operations that need to be taken before beginning to exchange data with the other devices of the network.

As may be seen in this figure, in the area of measurement 800 fluctuations appear on the measured curve: the router begins to transmit data at this phase, while around measurement 1300 the operation of the coordinator is stopped deliberately (powered off), and therefore the router is transmitting data with no receiver available. The router is configured so that never asks for acknowledgement of the transmittion, and therefore just keeps transmitting without caring about the lack of the coordinator. Nevertheless, the cc2480 transceiver itself has figured out the absence of a receiver, because now the fluctuations are of grater scale. This is due to the automated adjustment of the transmitted power which is included in the node under test.

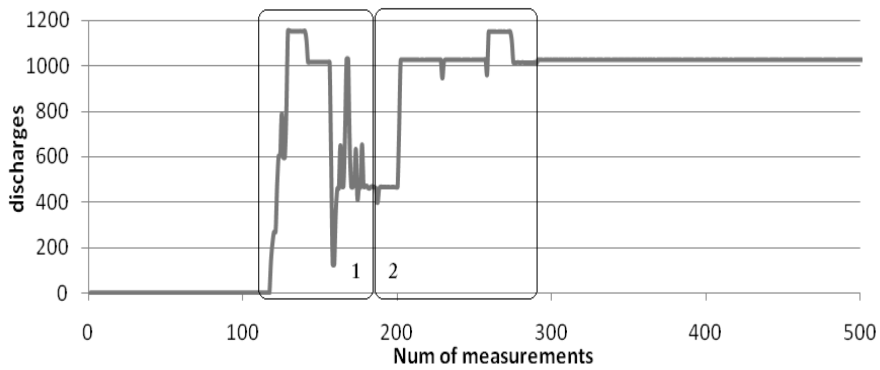

Fig.3. Starting procedure on the coordinator

Figure 3 shows the initializing procedure for the coordinator. The recorded variations look very similar to those of the initializations phase of the router provided, which is absolutely expected since the two types of nodes are actually the same devices until a specific step of starting procedure. The part that differs in this curve is part 2 (as it is noted on Fig. 3). This part is related to the coordinator starting the stack. After that, the energy consumption continues without fluctuations, which is corresponding to the coordinator waiting for other devices to be connected to the network.

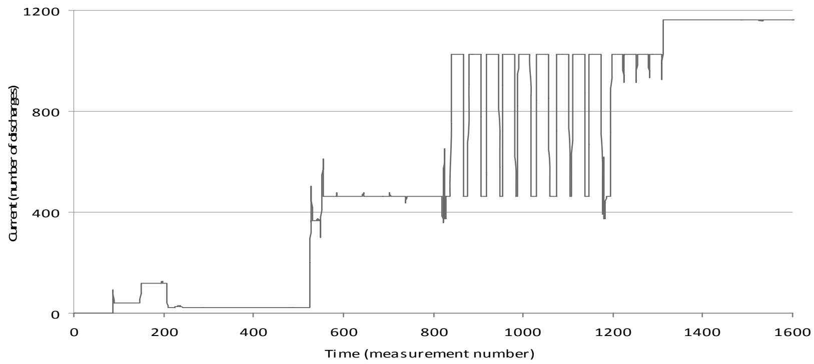

Fig.4. Starting up phase of a coordinator without any other node

The measurements shown in Figure 4 illustrate in terms of power-supply current variation thw operation of a coordinator unit without any other device available in the area. The measurements until number 700 are related to the starting operation of the microcontroller. For example the small ticks shown in the area of measurement 600-700 is corresponding to the consumption of a small LED blinking three times during start-up.

Then the device is configured as a coordinator unit, which (after measurement 1500) is waiting for other units to be connected to the network. This situation continues steady until a new device is powered on and connected to the network. Figure 5 shows the current variations of the same "coordinator" node when an end-device is powered on and connected to the network.

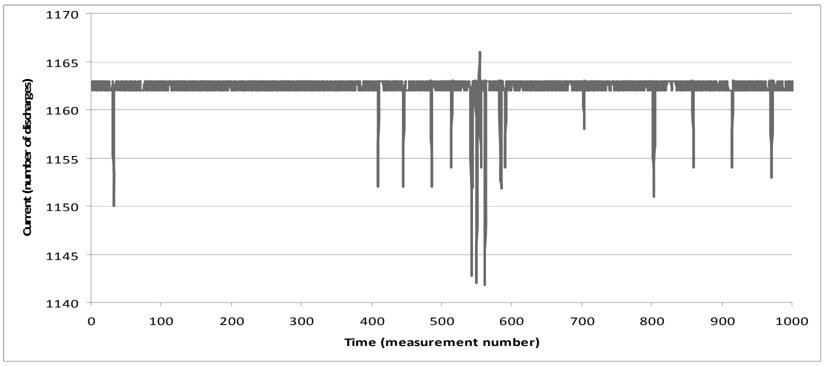

Fig.5. Handshaking phase of a coordinator when a new node (end-device) is connected

A similar, yet different in details picture is obtained for the power-supply current of the coordinator when another type of node is connected to the network. Figure 6 represents the current variations of the same coordinator unit when a router unit becomes available and is connected to the network. As may be seen in Fig. 3, 4 & 5, the average power consumption of the coordinator is the same (around 1162-63 discharges per measurement) for all three of the above situations: a)no other node (Fig.3, last phase), b)end-device connected, and c)router unit connected. Yet, the variations are different and by monitoring these variations one me understand the type of the new device connected to the network, by monitoring only the power-supply current at the coordinator.

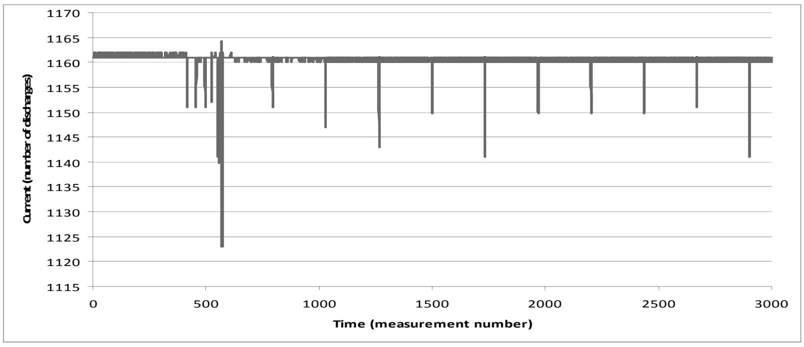

Fig.6. Handshaking phase of a coordinator when a new node (router) is connected

From these recordings is very clear that the coordinator is operating continuously without any reduction in the power consumption in the different phase of operation of the network (as expected by the ZIGBEE specifications). By contrast an end-device is capable of operating at low-power mode once connected to a network.

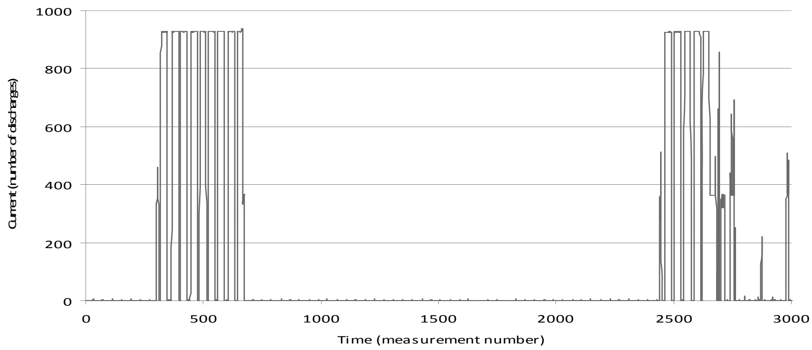

Fig.7. Power consumption of an end-device when it is NOT connected to a network

Such a phase of operation is shown in Fig. 7, where the variations of the power supply current of an end device are shown. The end device is operating without a connection to any network at the beginning of the recording, and it is clear that there are continuous intervals of high power transmission (looking for a network to connect) followed by very low-power time intervals. During the second burst a coordinator is found (was powered on) and then one may see short pulses of consumption during the communications phase (last part of Fig.7). Then the operation of the same end device when connected to a coordinator is shown in Fig.8. It is certainly clear the power consumption of the end-device is almost negligible during the idle periods of this situation, if compared with the power consumption of the same device when “looking for a network to connect”, or if compared with the average power consumption of the coordinator (with or without other units connected).

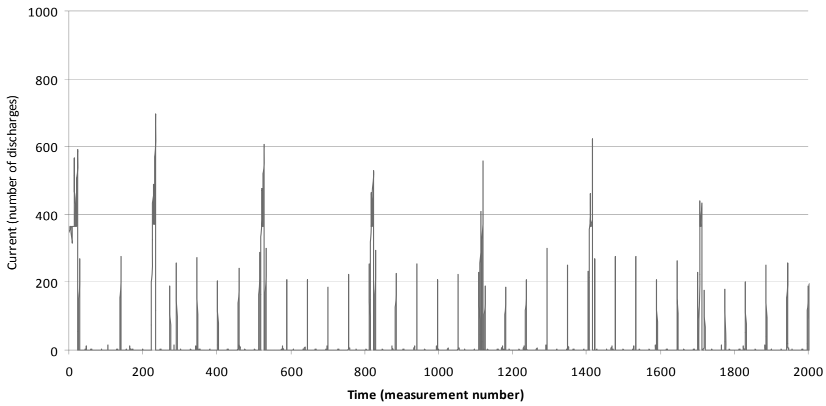

Fig.8. Power consumption of an end-device when connected to a network

V. CONCLUSIONS

The power consumption of ZIGBEE network nodes has been investigated by means of a novel measurement technique for monitoring power-supply-current variations of electronic units. A test network was built and studied experimentally and the results presented in this paper show a clear illustration of the operation of the nodes in terms of power consumption while executing standard procedures according to the ZIGBEE protocol. Specific operations have been detected and identified by analysing measurements of power consumption of a ZIGBEE node. The recordings of current variations illustrate the remarkable resolution of the proposed measuring approach.

References

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