Design and Implementation of Medium Access Control Based Routing on Real Wireless Sensor Networks Testbed

Smriti Agarwal, Ashish Payal, B. V. R. Reddy

Abstract**—**IEEE 802.15.4 is a Low Rate Wireless Personal Area Networks (LR-WPAN) standard combined with ZigBee, which is going to enable new applications in Wireless Sensor Networks (WSNs) and Internet of Things (IoT) domain. In recent years, it has become a popular standard for WSNs. Wireless communication among sensor motes, enabled by IEEE 802.15.4 standard, is extensively replacing the existing wired technology in a wide range of monitoring and control applications. Researchers have proposed a routing framework and mechanism that interacts with the IEEE 802.15.4 standard using software platform. In this paper, we have designed and implemented MAC based routing (MBR) based on IEEE 802.15.4 standard using a hardware platform "SENSEnuts". The experimental results include data through light and temperature sensors obtained from communication between PAN coordinator and source node through coordinator, MAC address of some modules used in the experimental setup, topology of the network created for simulation and the remaining battery power of the source node. Our experimental effort on a WSN Testbed has helped us in bridging the gap between theoretical and practical aspect of implementing IEEE 802.15.4 for WSNs applications.

Keywords**—**IEEE 802.15.4, routing, wireless sensor networks, ZigBee.

I. INTRODUCTION

INTERNET technologies coupled with new communication paradigms has led to the development of WSNs. Micro-Electro-mechanical systems have been enabled to construct smart tiny sensor motes with on board processors, sensors, memory, analog-to-digital converters (ADC), and transceivers in order to monitor a wide range of real-world phenomenon. A network of sensors is deployed to sense the environment with an ability to do some sort of data processing and further communicating to the base station. The environment can be the physical world, a biological system, or an information technology (IT) framework. The interconnecting network of sensors can be wired or wireless.

Wireless platforms are becoming less expensive and more powerful, enabling the promise of widespread use for everything from health monitoring to military sensing. Wireless networks have basically emerged from two different communities - telecommunication networks and computer data networks [1].

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In the last few years, WSNs drew the attention of the research community, driven by a wealth of theoretical and practical challenges. A wide variety of large and small WSN systems are being developed and used for sensing (e.g., reconnaissance, surveillance, and chemical/biological/nuclear) and other types of missions. With the extensive application of WSN, energy supply becomes the greatest problem of WSN. In a typical WSN, each sensor node operates with limited battery power and limited signal-processing capability; each sensor node communicates wirelessly with other nodes in its radio communication range.

WSN applications can be grouped into two broad categories: event based and periodic monitoring. Although these application categories may differ in terms of traffic characteristics and quality of service requirements, both categories essentially place the same communication architecture on the underlying network. This architecture is such that communication is generally between WSN nodes and their neighbors or between WSN nodes and the sink nodes. Communication between neighbor nodes is primarily one that allows for efficient data gathering. For example, data with regard to sensed phenomena can be aggregated or pruned to eliminate duplicates if nodes within the same vicinity cooperatively work with one another. These data are then transmitted to the sinks, where they are consumed. If these sink nodes reside one hop away from the data-gathering nodes, then the task of the data source to sink transmission is simple. However, these sinks may sometimes be located at multiple hops away from the source of the data, thus requiring a routing protocol. Depending on the application and network, architecture routing protocols are developed and implemented in WSNs.

IEEE 802.15 working group defined the specifications for IEEE 802.15.4 standard. The aim of this standard was to provide low-cost wireless link for all types of industrial and commercial sensor motes. The physical layer (PHY) and medium access control (MAC) sub layer specifications of IEEE Standard 802.15.4 ensures ultra-low power consumption with low data rat e for inexpensive sensor motes. Wireless Personal Area Networks (WPANs) provide seamless connectivity within short range.

II. RELATED WORK

Researchers have proposed and developed number of techniques for WSNs and IEEE 802.15.4. Zou and Wan [2] have studied the effect of eavesdropping attacker on an industrial sensor network. It consists of sink nodes and multiple motes.

Heo et al. [3] propose EARQ which is a novel routing protocol for wireless industrial sensor networks. It provides real-time, reliable delivery of a packet, while considering energy awareness. Lee et al. [4] propose a novel communication model relying on the typical sensor network model in order to effectively support both the remote users and the mobile users. Han et al. [5] address the problem of deploying a minimum number of relay nodes to achieve diverse levels of fault tolerance in the context of heterogeneous WSNs, where target nodes have different transmission radii.

Lu et al. conducted a simulation-based performance evaluation for IEEE 802.15.4 [6]. In [7], Misic et al. derived the probability distribution of access delay and calculated the throughput of a beacon-enabled IEEE 802.15.4 network. Zheng and Lee [8] investigated whether IEEE 802.15.4 is fit for ubiquitous networking. Golmie et al. [9] evaluated the performance of IEEE 802.15.4 for medical applications in terms of goodput, delay, and packet loss. Misic et al. [10] pointed out bottlenecks in the MAC layer of 802.15.4, but only simple solutions were proposed. Sheu et al. proposed a schedule strategy by utilizing an inactive period to disperse traffic load and promoted system performance [11]. However, they added new control frames which were not compatible with the IEEE 802.15.4 standard. Ting et al. [12] presented a performance evaluation of IEEE 802.11 against IEEE 802.15.4 with those power levels. Polepalli et al. performed many experiments to evaluate the performance of IEEE 802.11n and IEEE 802.15.4 when channel overlap happens in both types of networks [13]. Bhat et al. implement a small subset of the IEEE 802.15.4 protocol to achieve a point to point communication [14]. Lim et al. show that IEEE 802.15.4 transmission failures are largely due to channel access failures rather than corrupted data packets [15]. Yuan et al. present a coexistence model of IEEE 802.15.4 and IEEE 802.11 b/g which exposes the interactive behavior between these two standards and therefore accurately explains their coexistence performance [16]. Petrova et al. give a short overview of the IEEE 802.15.4 and carefully analyzes the properties and performance of IEEE802.15.4 through measurement of the RSSI, PER and run lengths distribution using real off-the-shelf hardware [17]. In [18], Yuan et al. propose a decentralized approach to help IEEE 802.15.4 nodes to mitigate interference. Bartolomeu and Fonseca present some preliminary results of an ongoing research regarding the IEEE 802.15.4 PHY immunity to the influence of standard IEEE 802.11 traffic [19].

III MAC Based Routing

MBR is based on IEEE 802.15.4 protocol which specifies the PHY and media access control for low-rate wireless personal area networks (LR-WPANs). Based on a communications perspective, an IEEE 802.15.4 node is functional only if it is associated with a WPAN, either as the coordinator or as a member. This section explains how MBR leverages the services offered by IEEE 802.15.4 standard.

MBR can be used when the destination is always the PAN Coordinator. As per IEEE 802.15.4, during the network setup, each node gets associated with a coordinator. In MBR, routing is done in such a way that every node sends the packet to the coordinator to which it is associated. This process keeps on repeating till the time that the packet is received by the destination node, i.e. PAN Coordinator. If the packet gets dropped, it generates an exception and the node resets itself. Fig. 1 shows the flow of data from right to left for MBR where the destination is PAN coordinator.

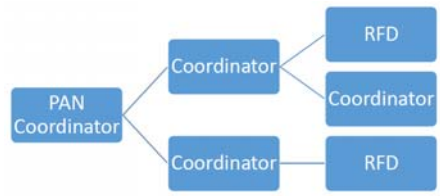


Fig. 1 MBR (from right to left)

In LR-WPAN following two different types of device operate:

a) Full-Function Device (FFD): It can work as main controller (PAN coordinator), coordinator, or a network device.
b) Reduced-Function Device (RFD): It can be implemented with minimal protocol dependencies with less amount of data to be transferred.

IV. Problem Definition

In the last few years, a number of routing protocols based on IEEE 802.15.4 standard were implemented, but they focus on software implementation and simulation through OPNET, FPGA, Verilog, etc. In difference to these routing protocols, the proposed routing protocol has been simulated and implemented in both software as well as hardware platform.

The objective is to implement MBR based on IEEE 802.15.4 standard on a hardware platform. Many routing protocols are proposed and implemented on software platforms like OPNET, ns-2, GloMoSim. The work presented here is to implement the proposed routing protocol for the IEEE 802.15.4 enabled WSN on a hardware platform. For hardware implementation and simulation of the proposed routing scheme, SENSENUTS tool kit is used. SENSEnuts allows a user to work on IEEE 802.15.4 and to harness the features with which a user can work on various research topics. SENSEnuts development platform has a wide variety of sensor modules which are compatible with Radio Module, the heart of the platform. They can directly be mounted on the Radio Module and the sensor related data can be reported to the microcontroller. SENSEnuts is a platform for WSN research, development and implementation. The platform finds its application in numerous domains, though the back-end is running on IEEE 802.15.4 standard.

A. Hardware Equipment

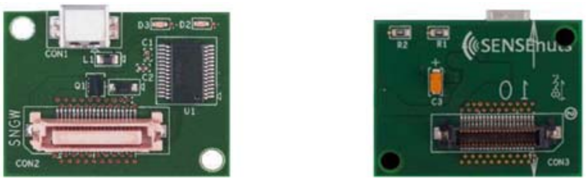
The hardware basically consists of:

- Radio module
- Sensor module
- Gateway module
- Battery holder
- Extender

Fig. 2 SENSEnuts device

Top View Bottom View

Fig. 3 Radio module



Top View Bottom View

Fig. 4 Gateway module

Fig. 5 Sensor module

Fig. 6 Battery module

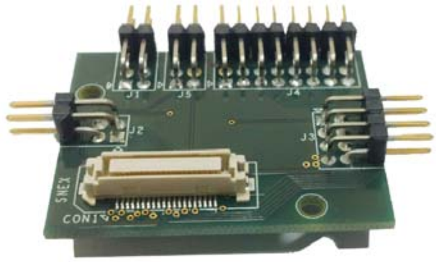


Fig. 7 Extender

V. Experimental Design

The minimal hardware needed for SENSEnuts devices is a gateway module (SNGW), a radio module (SNRD), and a USB cable for a connection between SENSEnuts platform and the user interface (Computer). Connect the USB mini cable to USB mini connector on the gateway module (CON1), and other end of the cable to the laptop or a PC. Connect the Radio Module with the Gateway Module by plugging CON3 on Gateway Module with CON1 on Radio Module (or CON2 on Gateway Module with CON2 on Radio Module). Turn on the switch (SW1) on the Radio module in order to start Radio Module. Open the SENSEnuts GUI and there will be a message stating "SENSEnuts device found". Now program the Radio Module or receive the data from the Radio Module connected with the system (if the module is previously programmed to send data to the system).

The radio module without sensor module_TL acts as PAN coordinator, and the radio module with sensor module_TL acts as coordinator. In the experimental setup for MBR, the node which senses the data will be flashed with MBR coordinator code and acts as source coordinator, and the node which is directly connected to PC will be flashed with MBR PAN coordinator code and acts as PAN coordinator. The node which acts as intermediate node (actually as a coordinator) will be flashed with modified MBR coordinator code, but it cannot be able to sense data in this situation. The LED of intermediate node blinks whenever the data pass through it. The PAN coordinator, after receiving data, displays it on PC as it is connected to PC through USB cable. Fig. 9 shows the experimental setup of MBR.

In MBR, the source node will send data only to associated coordinator till the link breaks. If the link breaks due to any reason, the source node will try to find out the new coordinator in its range for association.

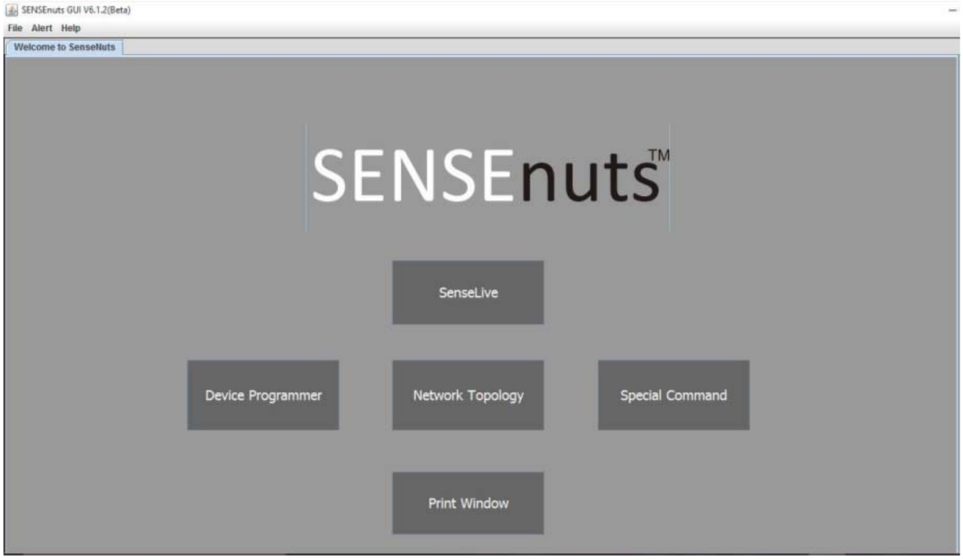


Fig. 8 GUI home screen

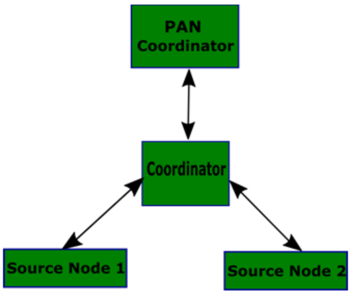


Fig. 9 Experimental set up of MBR

VI. Experimental Results and Analysis

The source coordinator senses the temperature and light of the surrounding environment, then sends these data to the coordinator (i.e. intermediate node) to which it is associated. The coordinator, after receiving the data from source coordinator, passes it to the PAN coordinator which acts as sink for this routing scheme. As the PAN coordinator is connected to PC, it will display the data coming through temperature and light sensors on the PC monitor.

Following are the results of the proposed work observed after flashing the appropriate codes of MBR in the motes. These results include the network topology, data of sensor modules received by PAN coordinator, MAC addresses of modules used in the experiments and remaining battery of source node in volts.

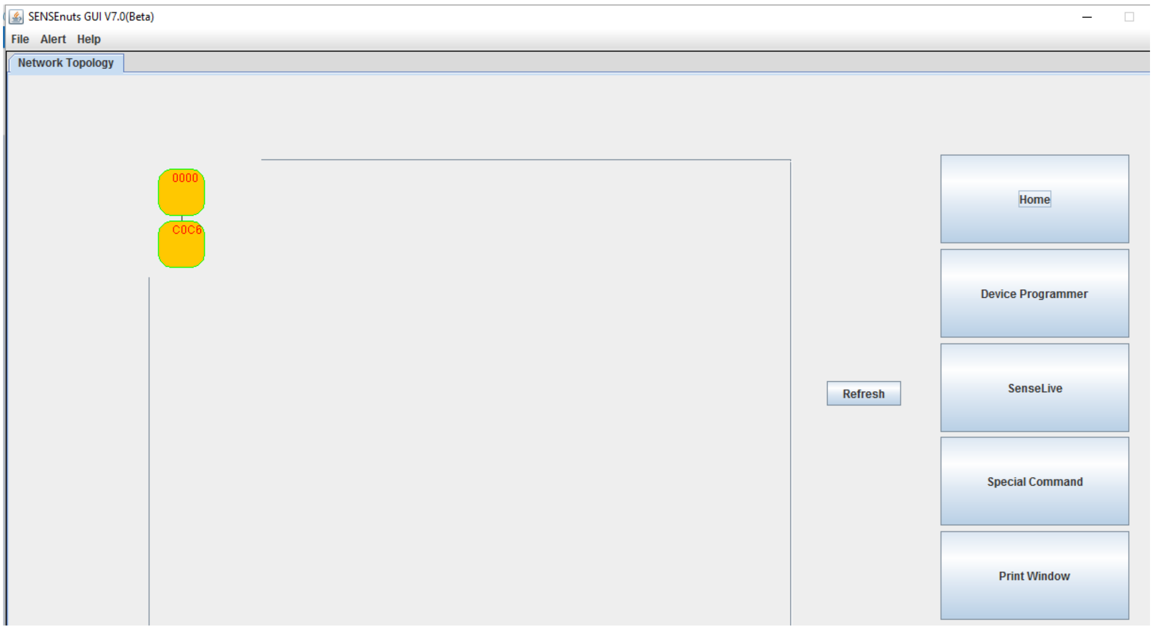


Fig. 10 Communication of PAN coordinator with one coordinator

Fig. 11 Communication of PAN coordinator with two coordinators

Fig. 12 Communication of PAN coordinator with three coordinators

A. Communication between Coordinator and PAN Coordinator

The following figures (Figs. 11-14) show the communication between coordinator (which is sensing temperature and light) and PAN coordinator (which receives data from coordinator). Up to three coordinators are used to show their simultaneous communication with PAN coordinator.

B. Communication through Coordinator

This topology actually shows the MBR. The PAN coordinator with destination address 0 will receive data from source nodes through coordinator. The source nodes associated with coordinator can communicate with PAN coordinator through this coordinator. Up to two source nodes are used here, which are sensing light and temperature using sensors and send their data through the associated coordinator.

C. Data from Source Coordinator

Source nodes are sensing light and temperature of the surrounding environment and sending data to PAN coordinator directly, and the PAN coordinator displays data of both the nodes one by one. These results have shown the variation in light and temperature when the node is placed in dark place.

D. Remaining Battery

The battery of the source node remained after its usage has been calculated by changing the codes of sensor modules. The source node sends its data of remaining battery to PAN coordinator through MBR, and then, PAN coordinator displays these data in "Print Window" screen of SENSEnuts in hex format. Then, these data in hex format have been converted into float format to get the remaining battery in volts.

Fig. 13 One node associated with coordinator

Fig. 14 Two nodes associated with coordinator

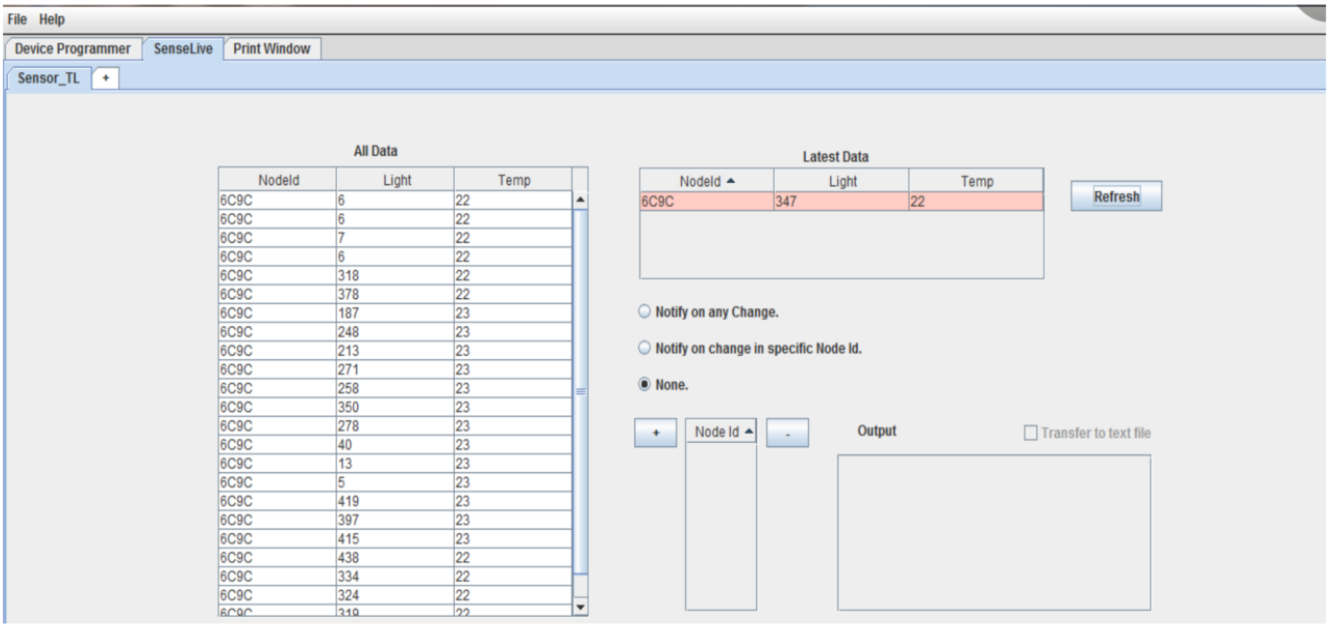


Fig. 15 Data from one source

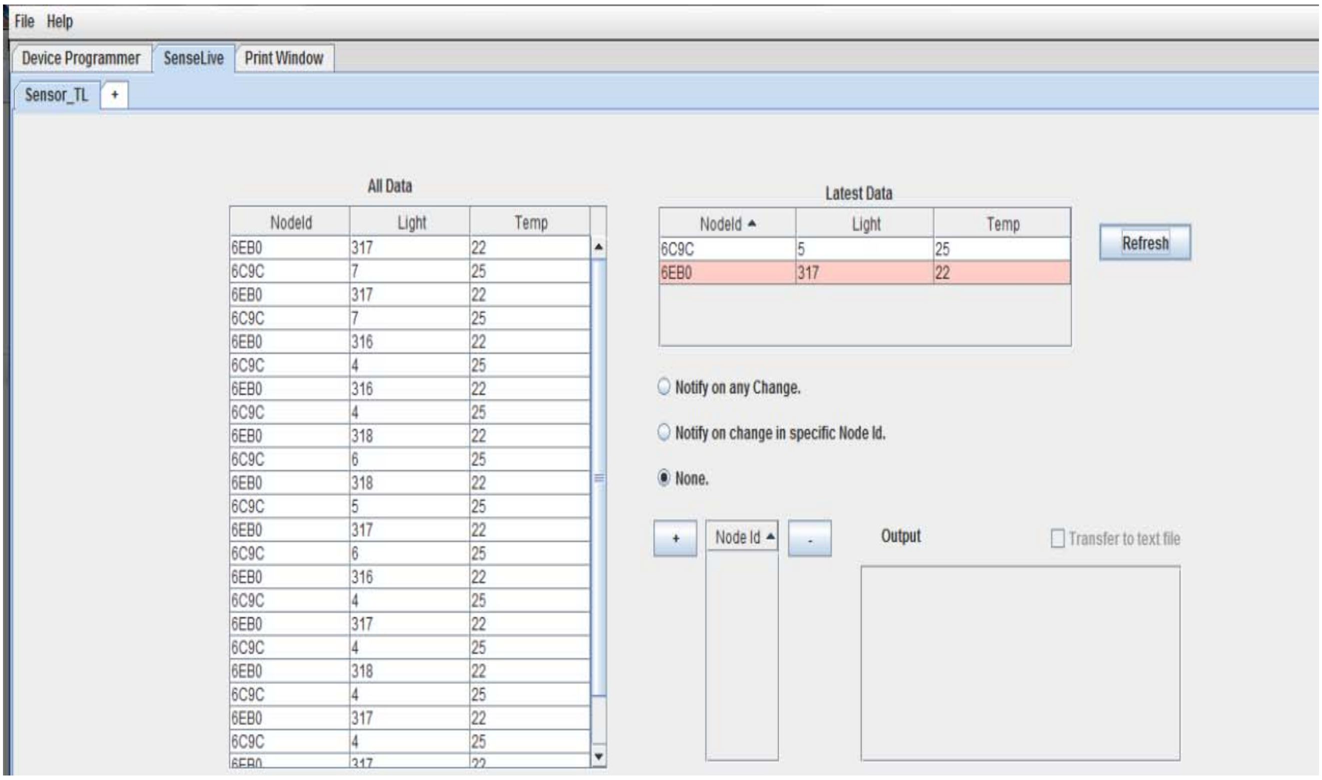


Fig. 16 Data from two sources

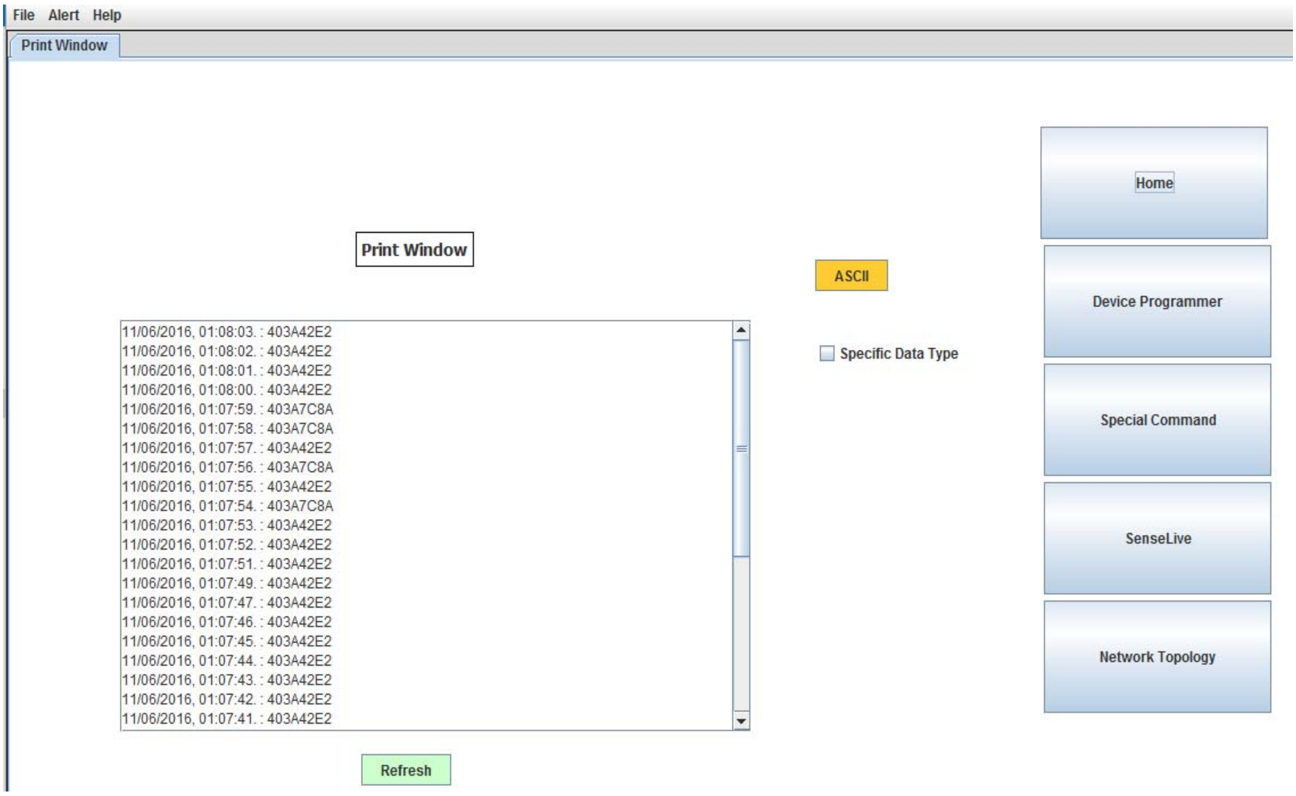


Fig. 17 Battery in hex format

Here, 403A42E2 in hex format gives 2.910332 in float format and 403A7C8A gives 2.913851. So, the remaining battery of the source node is around 2.91 V.

VI. Conclusions

A WSN has been successfully implemented on the SENSEnuts hardware platform which shows the MBR that is based on IEEE 802.15.4 standard. The platform used for IEEE 802.15.4 enabled WSNs is much better than previous software platforms because in SENSEnuts, the assumptions made in the simulation environment are automatically overruled as the transfer of data between the devices takes place through the actual medium, i.e. air with all available interferences. SENSEnuts takes into the real world scenario where algorithms can be tested on real devices. User can write his/her own algorithms and program the real motes according to the algorithm. The network topology has also been displayed in the network topology window of SENSEnuts GUI (beta) and the data of sensor modules has been shown in tabular form on the SENSEnuts GUI. During the simulation, it has also been observed that sending rapid continuous data to PC with a gateway connected on Radio Module may cause issues in reprogramming the nodes.

SENSEnuts is an integrated solution for 802.15.4 based applications and ideal for research and development purposes. IEEE 802.15.4 based WSNs can also be created through SENSEnuts platform. Throughput, latency, delay, power consumption and other parameters for MBR can also be calculated using this platform.

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