A Simulation Model of IEEE 802.15.4 in OMNeT++

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ABSTRACT
IEEE 802.15.4 defines the physical and MAC layer specifications for low-rate wireless personal area networks (WPANs). In order to evaluate its performance, we develop a simulation model of IEEE 802.15.4 in OMNeT++, which is a popular simulation platform especially suitable for the simulation of communication networks. The model consists of two modules for PHY and MAC layers respectively and supports star and cluster tree topologies. Our model is built conforming to the latest version - IEEE Std 802.15.4-2006 and has the extendibility to the ZigBee protocol stack.

Keywords
IEEE 802.15.4, simulation model, OMNeT++

1. INTRODUCTION
IEEE 802.15.4 [1] is a standard designed for low-rate wireless personal area networks (LR-WPAN) and defines the specifications at the physical layer (PHY) and medium access control (MAC) sublayer. In contrast to wireless local area network (WLAN), which is standardized by IEEE 802.11 family, LR-WPAN stresses short-range operation, low-data-rate, energy-efficiency and low-cost. Thus, LR-WPAN has become one of the most foreseen technologies enabling WSNs. An example is ZigBee [4], which is an open specification built on the LR-WPAN standard and targeted at low-cost, low-data-rate and low-power wireless networking.

OMNeT++ [2] is a public-source, component-based and discrete event simulation environment and is becoming a very popular simulation platform especially in communication and networking community. Its primary application area covers the simulation of communication networks, IT systems, queuing networks and business processes as well. [5] has shown that OMNeT++ is very suitable for simulating wireless sensor networks owing to its modular structure and using NED language for ease of simulation configuration.

In this paper, we present a simulation model of IEEE 802.15.4 in OMNeT++. It consists of two modules for PHY and MAC layers respectively and supports simulations of star and cluster tree topologies. The PHY model implements the complete functions defined in the specifications. The MAC model implements three data transfer modes (direct, indirect and GTS), beacon transmission and synchronization, complete CSMA-CA mechanism and partial PAN management functions, like association. To measure energy consumption of nodes. we implement an energy model in the MAC module. All parameters defined in the specification except for those for security functions are implemented in the model and adjustable in the OMNeT++ configuration file omnetpp.ini or in a C++ source file where the default values for the majority protocol parameters are stored.

The rest of the paper is organized as follows. In section 2, we give a brief description of 802.15.4. In section 3, the model of IEEE 802.15.4 in OMNeT++ will be introduced in detail. Section 4 concludes the paper and give a vision to the future work.

2. A BRIEF OVERVIEW OF IEEE 802.15.4
In this section, we give a brief overview of IEEE 802.15.4. Only those parts related to our model are introduced.

The IEEE 802.15.4 network can work in one of three ISM frequency bands and choose from a total of 27 channels. Two different types of devices are defined in an LR-WPAN, a full function device (FFD) and a reduced function device (RFD). An FFD can talk to any other device and serves as a PAN coordinator, a coordinator or a device. An RFD can only talk to an FFD node. The standard supports two network topologies, star and peer-to-peer. In the star network, the communication occurs only between devices and a single central controller, called the PAN coordinator, which manages the whole PAN. The peer-to-peer topology also has a PAN coordinator, however is differs from the star topology in that any devices can communicate with any other one as long as they are in range of one another. A special case of peer-to-peer topology is cluster tree, in which a node talks only to its parent or children nodes.

To achieve better energy-efficiency, the IEEE 802.15.4 can operate on beacon-enabled mode, for which a superframe structure is utilized. A super frame is bounded by periodically transmitted beacon frames, which allow nodes to associate with and synchronize to their coordinators. It con-

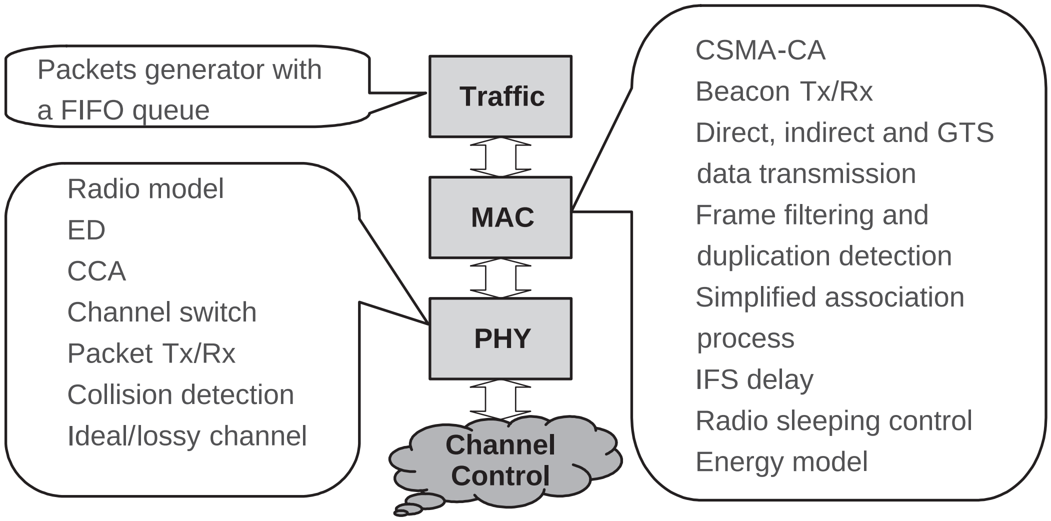

Figure 1: The structure and components of the 802.15.4 model

sists of two parts, active and inactive period. An active portion is divided into 16 contiguous time slots that form three parts: the beacon, contention access period (CAP) and contention-free period (CFP). In CAP, all data transmission should follow a successful execution of the slotted CSMA-CA algorithm. There are two data transfer modes defined in CAP, the indirect transmission for downlink data and the direct transmission for uplink data. In CFP, a device can communicate with the PAN coordinator directly in the called guaranteed time slots (GTS) without contending for the channel using CSMA-CA mechanism. The GTS are allocated by the PAN coordinator, therefor GTS transfer mode is only applicable in the star network.

3. DESCRIPTION OF IEEE 802.15.4 MODEL IN OMNET++

The IEEE 802.15.4 model is developed in the INET framework, which is an open-source communication networks simulation package for the OMNeT++ simulation environment and suited for simulations of wired, wireless and ad-hoc networks. The architecture of the 802.15.4 model is shown in Fig. 1. There are three sub models, traffic, MAC and PHY, each of which is a independent module and inherited from the basic C++ class *cSimpleModule* in OMNeT++. The modules are connected with each other via gates and communicate via messages. A snapshot of the model in the graphical interface of OMNeT++ called Tkenv is shown in Fig. 2. In the following sub sections, each of these modules is introduced in detail.

3.1 PHY Module

In the INET framework, a general radio module called *AbstractRadio* implements the common functionality of the radio, like packet transmission and reception with collision detection, channel switch, etc.. We adapt this module to create a proper radio model conforming to IEEE 802.15.4, by changing or adding the following contents:

- Redefine radio states: according to the specification, the radio is modeled with three states: transceiver disabled (TRX_OFF), transmitter enabled (TX_ON) and receiver enabled (RX_ON). The MAC module completely controls radio operation and can set the radio into different states via a request primitive. The PHY module reports the setting result back to the MAC via a confirm primitive.

- Clear channel access (CCA): the MAC module requires the PHY to perform CCA via the PLME-CCA.request primitive. The channel state (busy or idle) is determined in the model by checking two flags, *isRxing* and *isTxing*, which indicate whether the radio is currently receiving or transmitting packets. The PHY will set the flag *isRxing* by either of the following two facts: a packet (not a noise) is currently being received or the current noise level is above the sensitivity value. For a CCA request, checking flags will take place twice at both the beginning and the end of a period of 8 symbols. The CCA result will be reported back to the MAC via a corresponding confirm primitive.

In addition, the PHY module can be configured to work in any one of a total 27 channels and transmit packets at three different data rates, as defined in the specification. Dynamical channel switch during the simulation is also supported.

3.2 MAC Module

This is the main module in the whole model and contains the following three main parts:

3.2.1 Channel access

Channel access is the core function for any MAC protocol. We have implemented the majority functions and primitives for channel access defined in the specifications, including three data transfer modes (direct, indirect and GTS), MAC frame filtering, detection for duplicate received packets and the most important part - CSMA-CA mechanism

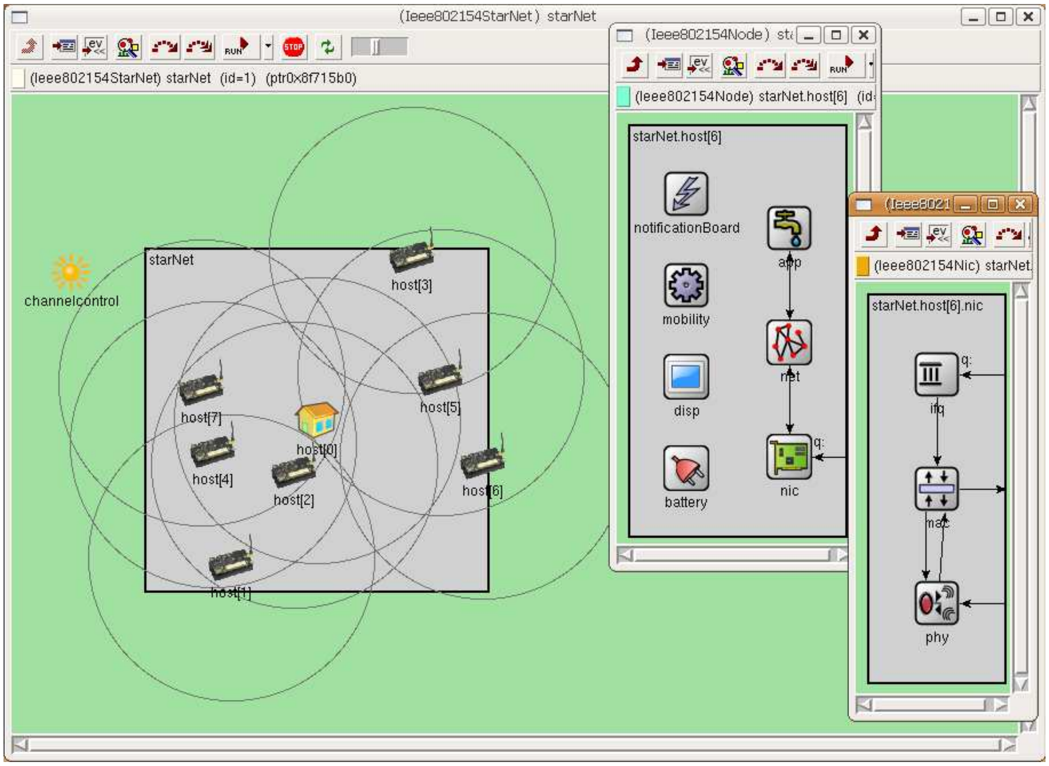

Figure 2: The 802.15.4 model in TKenv, the graphical interface of OMNeT++

(slotted and unslotted). To make the model more accurate, we also consider the IFS delay, which is defined as the required process time for a frame received from the PHY by the MAC.

3.2.2 Beacon mechanism and PAN management

IEEE 802.15.4 achieves good energy-efficiency owing to its beaconing mechanism. We implements in our model the complete beacon transmission and reception for nodes forming star and cluster tree network automatically. For example, to simulate a cluster tree topology, user can specify in the simulation setup phase which node to be the PAN coordinator and when to broadcast its first beacon. During the simulation running, when those nodes being placed one hop away from the PAN coordinator receive their first beacon from the PAN coordinator, they initiate the association process. After successful association, if those nodes are not leaf nodes, they will act as a coordinator and start transmitting beacons to those nodes placed at the next level in the cluster tree. When all leaf nodes are associated, the network forming phase is complete. With respect to PAN management functions, a simplified association process is modeled, that is, the node will associate with the coordinator, from which it receives the first beacon. Furthermore, loss of synchronization due to time drift (e.g. use of oscillator with $\pm 20ppm$) can be simulated with our model. Other PAN management functions, like channel scan and dissociation, are not considered in our model.

3.2.3 Energy model

Energy consumption is always a major interest in studying MAC protocols like IEEE 802.15.4 designed for energy-restricted wireless applications. In our model, we measure only the energy consumed at the radio. To achieve this in the MAC module, we let the MAC module keep tracking the current radio state in the PHY module via a message passing module defined in the INET framework called *NotificationBoard*. Therefor we only need to count the total time that the radio has spent in each state during the simulation. As long as the radio power for each state is known, the total energy consumption can be easily calculated. Although in our model we use a single state *RX_ON* to represent two possible working state in a real radio, idle listening and receiving, it is reasonable to assume that radios in these two states consume approximately the same power.

3.3 Traffic Module

The traffic module is not a part of IEEE 802.15.4, however we need a traffic generator to run the simulation. This module is modeled as the upper layers above the IEEE 802.15.4 model and acts as both a traffic source generating packets for the MAC module and a traffic sink collecting and analyzing received packets. The traffic module is inherited from the existing traffic generator class, which is implemented by Dietrich Isabel [3] and supports generating traffic with various types, including CBR, Exponential, and On-off. It uses a flexible XML-based parameter structure and supports dynamical change of traffic pattern during the simulation.

Table 1: Model Parameters

transmitterPower	power for sending packets (mW)
sensitivity	carrier sense threshold
thermalNoise	base noise level (dBm)
snirThreshold	signal/noise threshold
isPANCoor	is a PAN coordinator or not
BO	beacon order
SO	superframe order
startTime	when PAN starts beaconing

3.4 Model Parameters

Our model provides a vast amount of parameters adjustable for conducting a comprehensive study of IEEE 802.15.4. The default values for the majority protocol parameters are stored in a single C++ header file. We also put some parameters, which are most likely to be modified during the simulation, into the corresponding NED file for each simple module, so that user can change them conveniently in the simulation configuration file *omnetpp.ini*. Those parameters are listed in Table 1.

4. CONCLUSIONS AND FUTURE WORK

In this paper, we present a simulation model for IEEE Std. 802.15.4 developed in the popular simulation environment OMNeT++. Except for the PAN management and security functions, the model implements the majority parameters and functions defined in the specifications. Compared with the existing IEEE 802.15.4 model in ns-2, our model is built conforming to the latest IEEE Std. 802.15.4-2006 and implements the GTS data transfer mode, as well as an energy model. In the future work, more PAN management functions will be added to support simulating more complicated scenarios, e.g. mesh topology with ZigBee routing. A series of simulations for evaluating the performance of IEEE 802.15.4 in the QoS aspect are running. We also plan to integrate the security functions into our model and investigate how the performances are affected by those security mechanisms.

5. REFERENCES

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