Towards a WirelessHART module for the Ns-3 Simulator

Marcelo Nobre, Ivanovitch Silva and Luiz Affonso Guedes
Department of Computer Engineering and Automation (DCA)
Federal University of Rio Grande do Norte (UFRN)
Natal, RN, Brazil
marcelonobre, ivan, affonso@dca.ufrn.br

Paulo Portugal
DEEC/FEUP, University of Porto
Porto, Portugal
pportugal@fe.up.pt

Abstract

This work has the objective to present the first development results of a WirelessHART module for the ns-3. Our focus here is on the implementation of the Physical layer in order to provide basis to the development of the superior layers like MAC and Application. Thus, here is presented an energy consumption model, an error model based on Gilbert/Elliot and an analysis for the current ns-3 propagation loss models. For further development we mainly aim for the implementation of the time slot scheduler (Network Manager) and the development of inter protocol simulation with mutual interference.

1. Introduction

Nowadays, there is a visible expansion of the wireless networks over different areas, from multimedia traffic over metropolitan networks to local home networks . In order to support such expansion, simulation became a powerful tool due to its capability of providing a reliable approximation of how a topology or network design will behave for a more accurate design. The simulations can be used for evaluating new kinds of protocols without building expensive testbeds and also are easily scalable. In this paper, we intend to present our up-to-date achievements on developing a WirelessHART module for the Network Simulator 3 (ns-3) by demonstration a sort of models and preliminary results. The next sections will present an overview of the WirelessHART protocol and the ns-3, the proposal for our module, preliminary results and our conclusions.

2. WirelessHART

Before starting the overview description about the WirelessHART, it is important understand about the context where it was created. Highway Addressable Remote Transducer (HART) [1] protocol is one of the most successful field bus protocol nowadays and since 90s is available for industrial automation. Estimates that more than 24 million HART of devices are installed around the world and its shipping expectation is around over 2 million per year [5]. The WirelessHART concept was first discussed in 2004 at HART Communication Foundation (HCF) meeting. The main discussion was about means on how to interoperate legacy devices with wireless devices, taking advantage of the amount of HART devices already installed. In 2005, the HCF wireless working group was formed focusing on plant use cases and on keeping connection with the ISA100 committee. In September 2007, WirelessHART standard was published as part of the HART 7.0 specification. In September 2008, the WirelessHART specification (HART 7.1) was approved by the International Electrotechnical Comission (IEC) as a publicly available specification. The IEC name to the WirelessHART specification is IEC 62591 [[4]]. WirelessHART was the first industrial Wireless communication technology to attain this level of international recognition [12]. The standard is based on the physical layer of IEEE 802.15.4 [11] although a MAC layer of his own is implemented. However, some properties of IEEE 802.15.4 are not used. The only frequency adopted is the 2.450 Mhz band, the channels are only assignment to range between 11-25 and each channel has a 5 MHz band. The channel 26 is no longer supported due to the fact tha it is not compliant with the regulation of some regions in the world. Thus, just 15 channels are supported. In the, Also there is a new requirement on the WirelessHART specification that recommends the maximum switch time between channels be 0.192ms (12 symbols). However, despite these changes, the physical protocol data unit (PhPDU) used by the WirelessHART is the same as IEEE 802.15.4.

The medium access control is supported by a TDMA structured composed by superframes/slots, with each slot having duration of 10ms. The network can use diverse superframes, with different amount of slots, to attain multiples schedules requirements. All devices connected to the wireless network implement the basic mechanisms for supporting network formation, maintenance, routing, security and reliability. The network manager is the device responsible to generating routes and creating communication schedules in all network devices. Routes are generated based on mesh approach to guarantee the alternatives paths in case of communication link failures. The scheduler use frequency hopping and blacklist channels to provide reliable communications. The security manager is the device responsible by the security. There are three levels of security: hop-by-hop, end-to-end and per-to-per. The security is granted by the exchange of four different type of key: public, network, join and session. In relation to communication range, the distance supported between two devices is 100 meters. However, the specification indicate, but does not describe quantitative values, that is possible to achieve more distances depending upon the transmitter power, antenna type and lack of obstruction. The main difference between the layer physical of WirelessHART and IEEE 802.15.4 is related with the services. In the WirelessHART specification new services architectures were created. There are three types of services: control, message and management. The control service is used to enable or disable the transceiver whereas the message service is used to transfer data between physical layers. Finally, the management service is responsible for the physical layer attributes configuration.

3. Network Simulator 3

The Network Simulator 3 (ns-3) is free, open source discrete-event network simulator for internet systems. It is the successor of the ns-2, the most used network simulator in academia, although the ns-3 is not backwards-compatible with ns-2 [2]. For further reference, a large documentation is available on the Ns-3 project website. Ns-3 works with C++ language (Phyton language is optionally used) and was implemented using a object oriented structure, providing a modular environment in which various models could be reutilized making the software user friendly. [13] demonstrated that the ns-3 has a best overall performance for memory usage and run time over various recent network simulators (OMNet++, SimPy and Jist), surpassing even ns-2. Until this date there are no 802.15.4 modules for ns-3. This absence and the possibility to integrate different wireless technologies into the same simulated environment for a further coexistence study also takes part on our choice for the ns-3.

4. Proposal

Our Proposal consists on building a WirelessHART module for the NS-3, aiming for the advantages pointed on [13] and for the fact that the WirelessHART is being widely accepted as pattern for the industry. Also, the existing WirelessHART implementations of others simulators are proprietary softwares, meanwhile our simulator will be under a GNU GPLv2 license and available for all community. Until this date, only the Physical layer is already implemented. The structure can be seen in Figure 1.

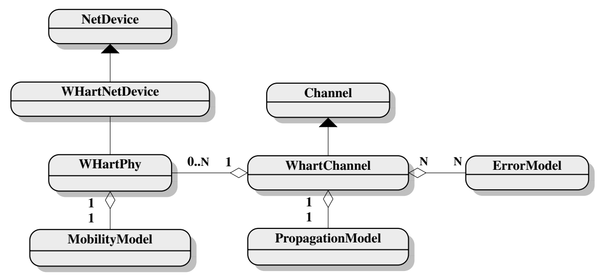

Figure 1. Class Diagram of the Physical of the WirelessHART

The classes NetDevice and Channel are standard classes of the ns-3, and must be extended for the implementation of the Link Layer and the medium characteristics, respectively. The class WHARTNetDevice stands for the preliminary implementation of the WirelessHART Link Layer features (those will be completed on the next steps of the software). The WHARTPhy class mantain the modeling of the radio transmitter of the simulated device, it includes characteristics such as signal detection level, the transmitter power and the model for the mobility of the device. For further studies over the energy consumption a radio model was developed based on the model presented by [8] and used data from the cc2520 radio transmitter ([7]). The radio state machine is described in Figure 2. There is presented the power consumption and current of each state and the energy and time spent on each transition.

The modeled states and the respective energy consumption of each, accordin to [7], are:

- Tx:The radio is transmitting (37,8mW).
- Rx:The radio is receiving (27mW).
- Idle:The clock is turned on and the radio is ready to switch to Tx or Rx state (2,7mW).
- Sleep:The clock disabled on and the radio is waiting to be turned on (1,62μW).

Finally, the WHARTChannel class models the characteristics of the medium which includes the 15 channels supported by the WirelessHART specification, the Propagation loss model and the Error Model.

The ErrorModel, MobilityModel and PropagationLossModel classes are native to the ns-3 core. The ErrorModel class provides error model but we choosed to

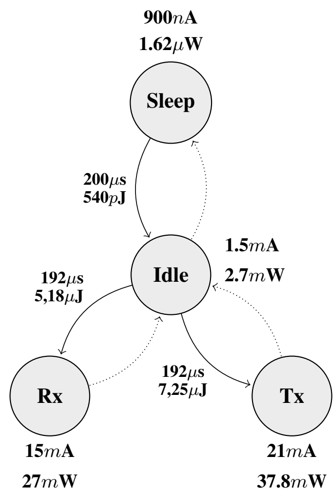

Figure 2. Energy model to the radio CC2520

implement a more accurate Gilbert/Elliot error model presented on [6] for wireless networks. This model calculates the Packet Error Rate (PER) value based on the size n of the packet. The model is based on the Markov chain presented on Figure 3.

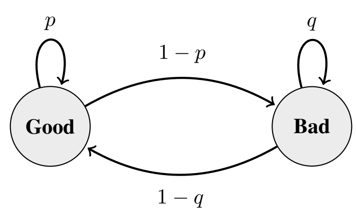

Figure 3. Gilbert/Elliot model error.

The initial state is the good state, and for each new bit, the channel can remain on or change a state. The transition probabilities are displayed on Figure 3, where p is the probability of being on a good state and remain on it, and q is the probability of being on a bad state and remain on it after a transition. Then, the steady state probabilities for good and bad states (P_g e P_b, respectively) are calculated by:

$$P_g = \frac{1-q}{2-(p+q)} \qquad P_g = \frac{1-p}{2-(p+q)} \tag{1}$$

Finally, the equation presented on [6] for calculating the Packet Error Rate(PER) for a n-byte message is:

$$PER(n) = 1 - (P_g p^{8n} + P_b(1-q)p^{8n-1}) \tag{2}$$

The mobility model provides the 3D position of a node, the simulation spatial limits and can also modelize nodes movimentation which includes constant speed, constant acceleration and fixed position for example, although this kind of functionality will only be used for the handheld device type, since the other devices must have constant positions according to [4]. The propagation model determines the propagation loss through a transmission medium. Calculating the receive power based on the positioning of the receiver/transmitter and the transmitter radio power. According to the documentation on [[2]], the ns-3 natively implements, for exemple, the following propagation loss models: Constant propagation, Fixed Rss Loss, Friis, Log Distance, Matrix, Nakagami, Random, Three Log Distance and Two Ray Ground[2].

For simplification purposes, the implementation of the different devices roles defined on the WirelessHART norm were omitted from the class diagram, but each device would extends WHartNetDevice. The kinds of devices that are specified in [4] and shown in Figure 4 are: router, adapter, handheld, gateway , field device and network manager. Among those, the network manager has its class diagram defined on the [4], being this diagram fully implemented over the Network manager class that extends WHARTDevice class.

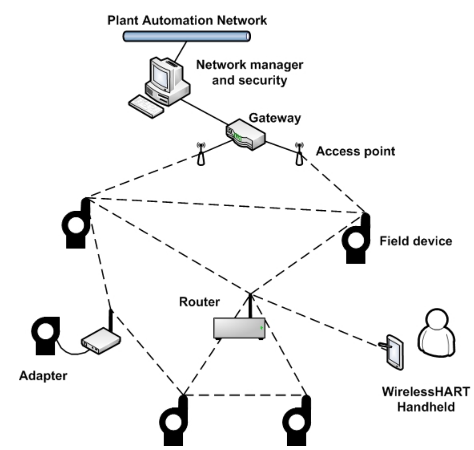

Figure 4. WirelessHART Devices.

5. Preliminary Results

As preliminary results, in Figure 5 is presented the signal propagation behavior for the Friss, Two Ray Ground and Log Distance models.

As can be seen, the signal strength declines with the distance and reach the radio perception limit of -85dB [4] around the 200 meters distance for the Friis model, 160 meters for the Two Ray Ground Model and 20 meter for the Log Distance model. This results were expected due to the fact that, although the range specified on [4] is 100m, the Friis and Two Ray Ground models are projected for outside environments and assumes the ideal propagation condition that there is only one clear line-of-sight path between the transmitter and receiver whereas the Log Distance is designed for inside a building or densely populated a environments [9]. All the models used wavelength of 0,125m and the unitary antenna gains.

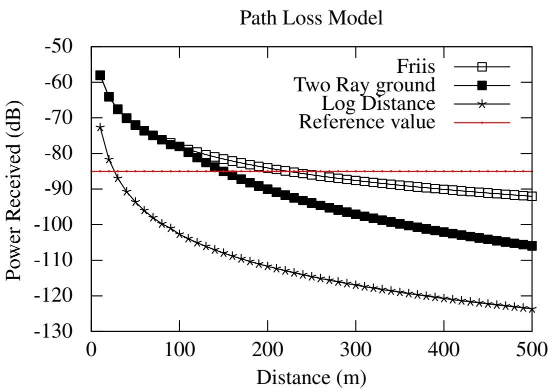

Figure 5. Received Power X Distance

In the Figure 6, the error rate measured over 10000 packets sent between two stations for each different packet sizes. The probability parameters for the Gilbert/Elliot modelare: p is 0,99999 and q is 0,999. The most common WirelessHART messages were chosen (Ack-9 Bytes, Advertise-18 Bytes, Keep-Alive-6 Bytes and Maximum Packet Size-133 Bytes) and also a common application packet size for the petrochemical industry (90 Bytes) found on [10]. As can be seen in Figure 6, the PER values

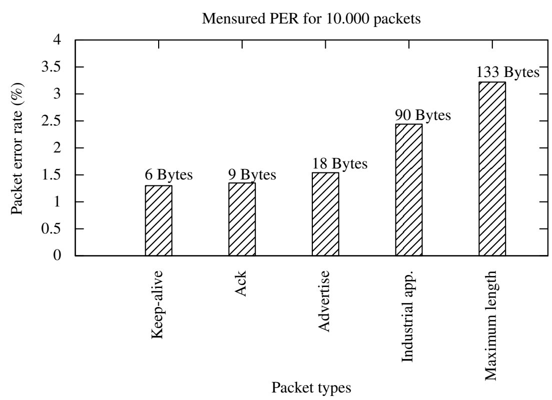

Figure 6. Packet error rate for different WirelessHart packets.

grow with the packet size as expected from the behavior of a Gilbert/Elliot implementation, like the one presented in [6].

6. Next Steps

As next steps we intend as main objective to build the network manager for scheduling the the time slots for each station, the construction of the channel's black list (devices avoids noisy channels), channel hops, tools for a animated display of the simulation process, simulate energy consumption by the stations and analyze the behavior of different Physical layers configurations(Sorting propagation loss, error and mobility models). Furthermore we intend to develop an WirelessHart (802.15.4 based) simulation that can support coexistence with different networks, such as with Wifi, that uses common frequency channels as proposed on [3].

7. Conclusion

Preliminary results were demonstrated that the project is evolving to the planned direction of the initial sketches. The object oriented format of the ns-3 project shown itself to be easily learned and used due to its organization and vast available documentation. A first modelation for the energy consumption were presented. The Position and Propagation Loss models natively supported by the ns-3 were successfully used. And finally, the Gilbert/Elliot Error model was successfully implemented.

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