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Monitoring the Delay and Directivity of Antennas in Gigabit WPAN (802.15.3c)

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***Abstract*— The IEEE 802.15.3 is an ad hoc MAC layer suitable for multimedia WPAN applications and a PHY capable of data rates in excess of 20 Mbps. In 2.4 GHz unlicensed band, IEEE 802.15.3 specifies data rates up to 55 MBPS. It basically employs an ad hoc PAN topology, with roles for "master" and "slave" devices.In this work, it needs to determine the delay in discovering the devices by Pico Net Controller (PNC) and the most efficient antenna pattern so as to achieve maximum throughput and as a result increase in the QoS. At the beginning of each super-frame, a network beacon is transmitted which carries WPAN-specific parameters, including power management, and information for new devices to join the ad hoc network. PNC sends beacons to various devices and the device, which accepts the beacon, sends an acknowledgment frame to PNC. When the devices are connected to PNC, the piconet is formed through which PNC and devices can communicate with each other. For the performance assessment of the wireless networks using antennas, baseline models of directional antenna and isotropic antennas have been developed using the simulator OPNET Modeler^{TM} 12.0. The code developed is to be such that, it can be easily extended to a real time implementation. From the results of the simulation it is observed that although the models with isotropic antennas have good throughput, the maximum is achieved by using directional antenna models. Moreover, use of directional antennas at transmitter and receiver decreases in end-to-end delay. For simulation, licence version of OPNET Modeler^{TM} 12.0 is used.**

***Keywords*— PNC, QoS, piconets, DEVs, throughput**

I. Introduction

Wireless personal area networks (WPANs) have become a ubiquitous technology to support broadband multimedia and high rate data applications in a small cell radius. They are expected to replace high-speed cable to connect wireless peripherals at home and in the future office. WPANs are having some particular features, including high data rate, low power transmission in a short range and possible multiple accesses, etc which allows a number of independent data devices to communicate with each other with a good QoS. [1]

Here, 12.0 release of the OPNET modeler software is used for achieving the aims.

The problems can be solved by building various models in OPNET like:

- Network model
- Node model
- Process model and by gathering information and analyzing them.

Basically, the performance of WPAN and more specifically about the directivity of antennas and delay in device discovery are tested.

The specific reason for using OPNET as this software is due to following reasons:

1. OPNET provides directional antenna support both at transmitter and receiver.
2. It provides graphical editor for creating antenna patterns.

Among a few wireless communication such like bluetooth, WLAN (Wireless Local Area Network) and WPAN (Wireless Personal Area Network), WPAN is holding the most leading technology for wireless home networking when considering assurance of QoS and short distance in house. Especially, as the utilization of wireless communication, voice and multimedia data is on the increase, the importance of QoS (Quality of Service) is gaining its significance. WPAN adopted peer-to-peer communication between the devices in the piconet as a basic access network. [3]

IEEE 802.15.3 is designed to enable wireless connectivity of high speed of Low power, low cost, multimedia-capable devices. This standard provides data rates of 11 to 55 Mbps at distances greater than 70 m while the QoS for the data stream is also maintained. In addition to that, devices can automatically form networks and exchange information without the direct involvement of user. There are varieties of techniques available, which can be used to enhance the QoS of 802.15.3 piconets. [2]

One of them is selection of appropriate antenna patterns of the piconet devices for transmission and reception of packets.

Piconet

Within a personal operation space, various devices are operating under the control of a piconet controller (PNC) in order to share a wireless resource. Basic timing is always provided by the PNC for the WPAN. Additionally the quality of service (QoS) requirements of the WPAN is also managed by PNC.

A piconet is basically a wireless ad hoc data communications system, which allows number of independent data devices (DEVs) to communicate with each other. In contrast to local area network (LAN), metropolitan area network (MAN), and wide area network (WAN), which covers a successively larger geographic area, such as a single building or a campus or that would interconnect facilities in different parts of a country or of the world, piconet networks are normally confined to a small area around person or object that typically covers at least 10 m in all directions and envelops the person or a thing whether stationary or in motion.

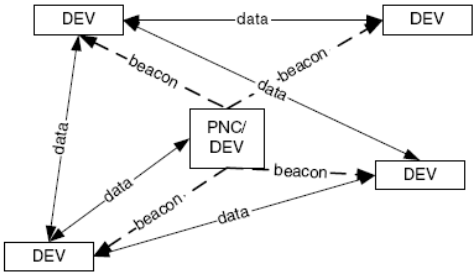


Figure 1 802.15.3 piconet elements [2]

An 802.15.3 piconet is having several components as shown in figure 1. The two main elements are DEV and PNC. DEV is the basic component. One of the DEV is required to assume the role of the piconet controller (PNC) of the piconet. The PNC always provides the basic timing for the WPAN. Additionally the PNC manages the quality of service (QoS) requirements of the WPAN.

As 802.15.3 piconets form without pre-planning and for only as long as the piconet is needed, this type of operation is referred to as an ad hoc network.

FCS field contains a 32-bit CRC. The msb of the FCS is the coefficient of the highest order term and the field is sent over the wireless medium.

IE's are encoded in type, length, value format and are defined in table 1 [2]

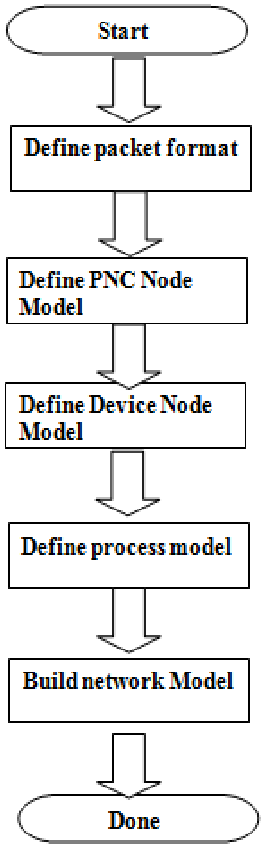
TABLE I
INFORMATION ELEMENTS

Element ID hex value	Element	Present in beacon
0X00	Channel time allocation	As needed
0X01	BSID	In every beacon
0X02	Parent piconet	As needed
0X03	DEV association	As needed
0X04	PNC shutdown	As needed
0X05	Piconet parameter change	As needed
0X06	Application specific	As needed
0X07	Pending channel time map	As needed
0X08	PNC handover	As needed
0X09	CTA status	As needed

In the past, there have been several studies regarding the performance of Mobile Ad-Hoc Networks (MANET) using directional antennas [13] [16] [17] [18]. A MAC protocol for MANETs is proposed by Ko, Shankarkumar and Vaidya [16] using directional antennas in which CTS frames are always transmitted omni-directionally, while RTS control frames are transmitted directionally or omni-directionally if the channel is clear for all directions. In the previous scheme the exact location of the targets are known using GPS. Another MAC protocol proposed by Nasipuri, Ye et al. [17] does not require additional hardware to identify the directions of specific nodes. Infact, it calculates using the received power from each (sectorized) antenna upon each signal reception. Frames are transmitted omni-directionally in this study. Sanchez, Giles and Zander [18] studied effects of RTS frames transmitted directionally and omni-directionally along with three different beamwidth patterns, and reported that the directional RTS transmission always outperformed the omni-directional RTS transmission. Ramanathan [13] studied the effects of directional antennas with omni-directional transmission of RTS and CTS, but also studied several other aspects of directional communication including power control and neighbor discovery in MANETs. All these previous studies discuss only the transmitter side beamforming, while directional antennas can be used for both transmitting and receiving. A model is designed, which supports both directional transmission and reception, and further allows directional transmissions of all frames. Further, there is no discussion as to whether these nodes are operational with omni-directional antennas using gigabit WPAN standards. The implementation of this model is according to WPAN standards through which the performance of the network can be analyzed by using directional and isotropic antennas.

II. DETAILS OF SIMULATION SET UP

Algorithm for making a simulation model:



Packet Format:

The packet format editor is used to create packets containing any number of different fields that affect packet size.

The packets in this network contain the beacon frame parameters and MAC header fields together. When the packet format is created, it can be specified in the generator, as an attribute so that packets created by the generator will be formatted accordingly.

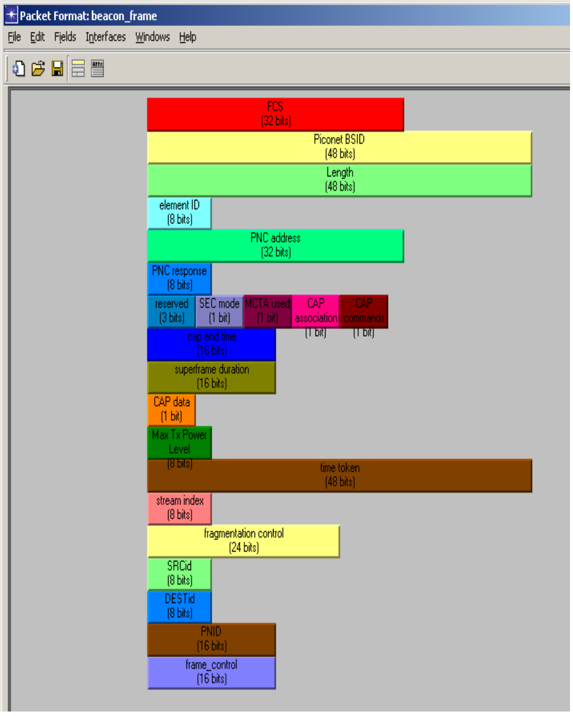


Figure 2 Beacon and MAC header packet format

PNC Node Model:

A node model is composed of a series of connected blocks called modules. Each module contains a set of inputs and outputs, some state memory, and a method for computing the module's outputs from its inputs and its state memory. A node model specifies the manner in which the inputs and outputs of various modules are connected using objects called connections. There are two types of connections, one to carry data packets, and one to transmit individual values. A module can send data packets over its output packet streams, and receive them from its input stream. [9]

Antenna Model:

The **antenna module** models the directional gain of a physical antenna by referencing its pattern attribute. The antenna uses two different patterns: the isotropic pattern (which has uniform gain in all directions) and a directional pattern that will be defined.

A new antenna pattern will be created, with a gain of about 200 dB in one direction and a gain of about 0 dB in all other directions (a *very* directional antenna).

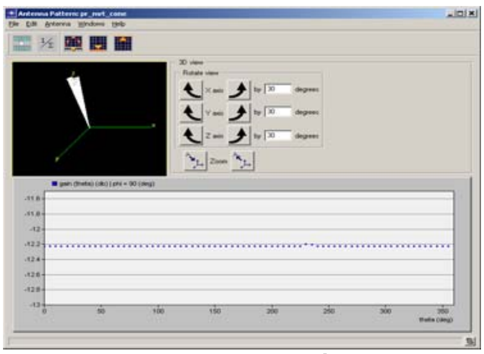


Figure 3 Antenna pattern editors

The graph panel displays the new ordinate range. This range will make it easier to enter the desired gain accurately.

Now that the graph panel has been set, specify sample points for phi = 5 degrees, as follows: Move the cursor as close to the 200 dB line as possible and left-click on the first sample point (0 degrees) in the graph. Move the cursor to the far right (still on the 200 dB line) and left-click on the second point (355 degrees).

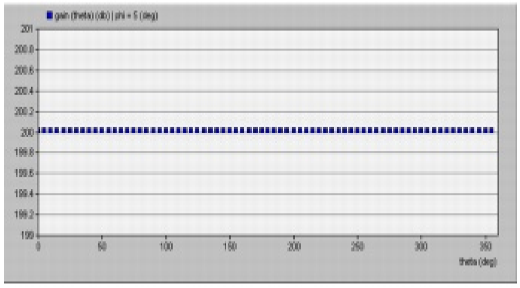


Figure 4 Specifying Sample Points

All sample points in between the two specified points are set automatically with linearly interpolated gain values. A dotted line marks the range of sample points.

When points in the graph panel are defined, the 3D projection view displays a cone-shaped shell of gain values for phi = 5 degrees to phi = 10 degrees and for theta = 0 degrees to theta = 360 degrees.

Now that the gain values are specified for phi = 5 degrees, it is needed to change the slice setting to 0 degrees, and then set the gain and sample points for this slice; doing so specifies a gain of about 200 dB for **phi = 0–5 degrees** and for **theta = 0–360 degrees**. This "fills in" the cone-shaped shell specified in the phi = 5 degrees plane.

The 3D projection view updates, displaying the result of normalization.

Antenna pointing processor:

The antenna pointing processor calculates the position of the PNC/DEV module and sets the antenna module's targeting attributes. It receives only a begin-simulation interrupt, so it can be designed as a single unforced state.

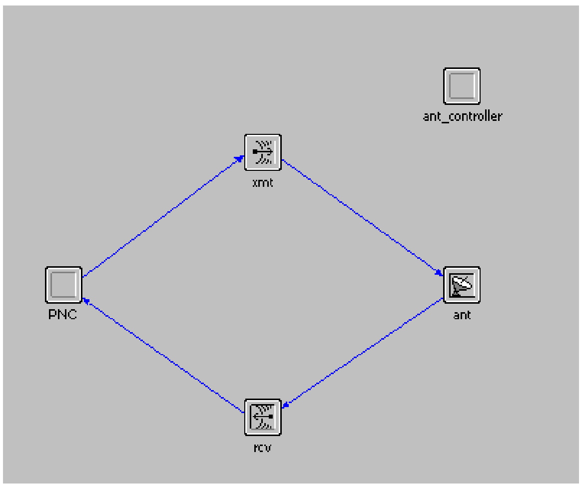


Figure 5 PNC node model

To run parameterized simulations, the **power** attribute of the utilized channel must be promoted. When the attribute is promoted, it can be changed easily at simulation run time.

All the parameters are according to the WPAN standards.

The simulation parameters:

TABLE III
PAPERS PARAMETERS

Data Rate	1 Gbps
Frequency	60 Gbps
Modulation	Bpsk
Power	.005 W
Bandwidth	2080 MHz

Repeat similar steps for **rcv module** while using the same parameters for receiver as that of transmitter.

PNC Process model:

Process models are used to specify the behavior of processor and queue modules, which exist in the node domain. OPNET process models can be used to implement a wide variety of hardware and software subsystems.

Proto-C models consist of two basic component types: states and transitions, hence the name state transition diagram (STD). States are generally used to represent the top-level modes that a process can enter. Transitions specify the changes in state that are possible for the process. [9] There are mainly three states:

- Initial state
- Forced state: does not allow pause during the process (Green)
- Unforced state: allows pause during the process (Red)

PNC processor module is connected to the transmitters and receivers by packet streams. As each packet is associated with an interrupt, the PNC process model receives an interrupt for sending beacons after repeated intervals to the devices, which accepts it and sends back an acknowledgement if they received the beacon and the piconet is initiated. Now, create the PNC process model. In this node model, there are four states, which include initialisation state (forced state), idle state (unforced state), send beacon state (forced state) and receive packet state (forced state).

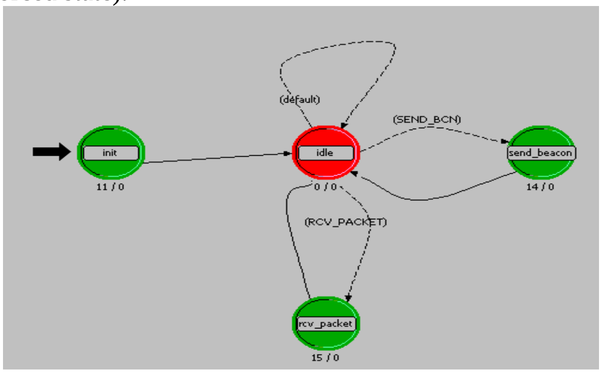


Figure 6 PNC process model

Header block:

Almost all macros used by a Proto-c model are defined in its header block. The header block is a free-form area for C language code, similar to the top portion of a C file. Macros are generally used to represent constants, transition conditions, transition executives, or commonly performed operations. [9]

Initialization header block

Initialization block is a forced state and as a result the process will proceed to a second state immediately after the initial state has completed; however, since the initial interrupt is a mainstream interrupt, it is correct to process this interrupt by performing additional actions. Thus, the conditional transitions out of the initial state may guide the process into several possible second states, where processing of the interrupt can take place.

State variables:

Variables that are used to represent the information accumulated and retained by a process are referred to as state variables. This name is due to the fact that these variables, together with the current position of a process within its state transition diagram, represent the complete state of a process at any time. [9]

State variables are declared in a dedicated area of a Proto-C model, referred to as the state variable block. The variables have been defined, which are used, in the process as shown below:

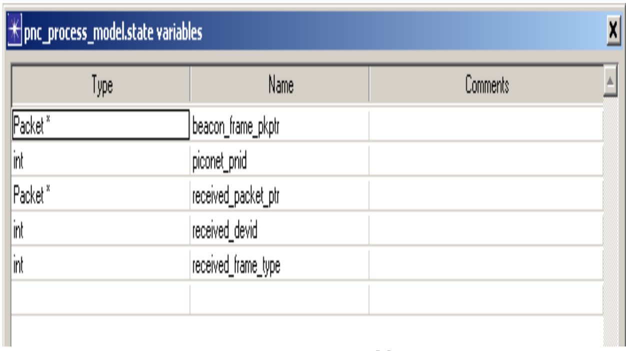


Figure 7 State variables

Beacon header block

When the initialization block receives an interrupt to send beacon, it will directly jump to the send beacon process block. A pointer is given to the beacon frame, which is shown below, and a command "op_pk_create_fmt" is used which creates a new formatted packet with a predefined structure described by the specified packet format. The packet format is already defined in figure 7 as Beacon and MAC header frame format. Now, the pointer will be assigned to the packet of interest and the value, which is to be assigned to the field of interest. This can be done by using the command: op_pk_nfd_set (pkptr, field_name, value).

Receive packet header block

Another block in process model is the receive packet block. When the devices will send the acknowledgment on the reception of beacon, this block will be activated and it will than go back to idle state.

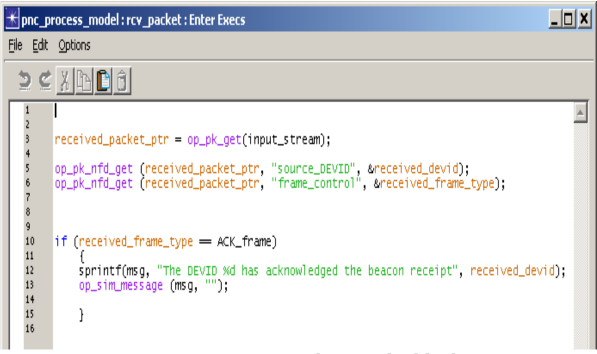


Figure 8 Receive packet Header block

This block will obtains a pointer to packet that has arrived on an input packet stream using the command op_pk_get(), and removes the packet from the stream. The next step is to obtain the pointer to the packets, which are of interest, and as this is receiver block, it will get the pointer for device id and frame control. .

Device node model:

Now a device node model will be designed, which includes a processor, transmitter module, receiver module, antenna module and another processor module, which is used to get the attributes of transmitter. The antenna pattern can be changed with the help of antenna controller. If antenna pattern is isotropic, antenna controller is of no use but when the receiver antenna is to be directed towards transmitter, the **processor module** (called a "antenna controller" in this model) calculates the information that the antenna needs to point at a target: latitude, longitude, and altitude coordinates.

The pointing processor makes this calculation by using a Kernel Procedure that converts a node's position in a subnet (described by the x position and y position attributes) into the global coordinates that the antenna requires.

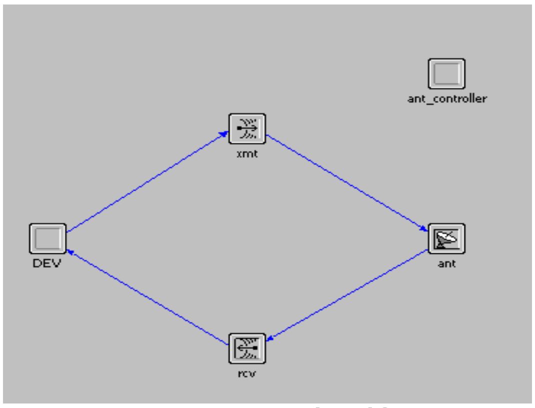


Figure 9 Device node model

Device process model:

The node process model deals with the sending the beacon frame to devices and receiving the acknowledgement from them, but device process model's main function is to compare the received beacon with the information, which is in the frame control field, and it also checks the PNID.

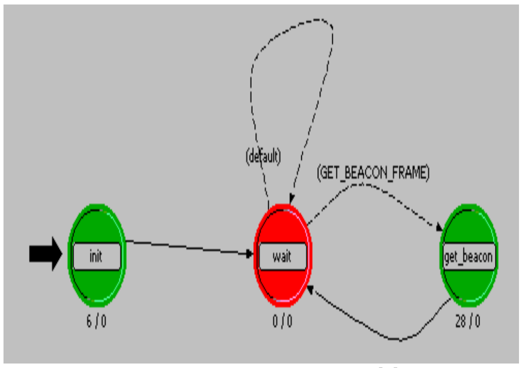


Figure 10 Device process model

The above process model consists of three stages including initialization, wait and send beacon state. Initialtization and get beacon state are forced while wait state is unforced. A default stream is feed back to wait state in-case if it receives interrupt from other sources, it returns back to its own state and not to any other useful state.

Now, the get beacon block will check if the received frame type is same as that send by the PNC, than it will create an acknowledge frame which is shown below:

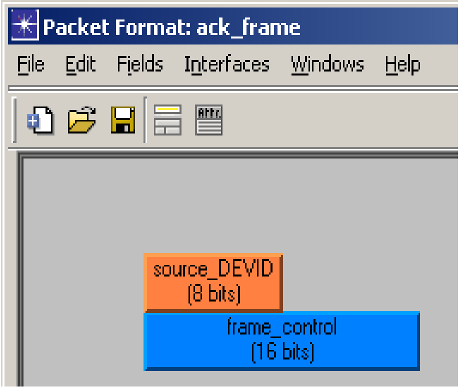


Figure 11 Acknowledgement frame

It assigns itself a device id so that PNC can know that which device is sending the beacon.

An acknowledgement frame is sent to PNC via output stream.

Building Network model

Network models are composed of the following main building blocks: subnetworks, communication nodes, and communication links.

A subnetwork encapsulates other network level objects. Communication nodes model network objects with definable internal structure. Communication links provide a mechanism to transport information between communication nodes.

TABLE IIII
SCENARIO PARAMETERS

Dialogue box name	Value
Initial topology	Default value: Create empty scenario
Choose network scale	Campus ("use metric units" enabled)
Specify size	100 * 100 meters
Select technologies	None
Review	Check values, than finish

In this model, a piconet is formed for a campus network with size of 100 meters * 100 meters. PNC is surrounded by six devices and when PNC will send beacon, each of the devices which are receiving the beacons will send an acknowledgement to PNC. The throughput can be monitored between PNC and devices by using various scenarios.

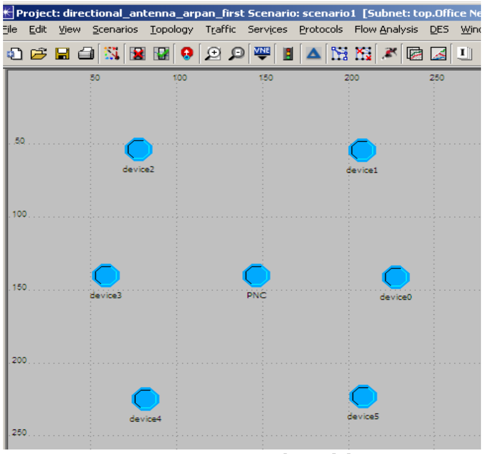


Figure 12 Network model

In this project, four scenarios are going to be used to test the throughput and delay, which are as follows:

Scenario A:

In this scenario, all the nodes use omni-directional antennas for transmission and reception of packets.

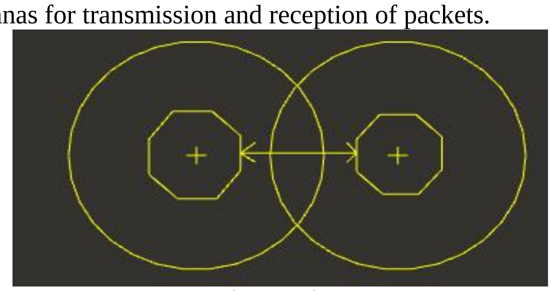


Figure 13 Omni directional antenna scenarios

Scenario B:

In this scenario, directional antenna is used by PNC for sending the beacon and data packets, while peripheral devices are using omni-directional antennas for sending acknowledgement and data packets.

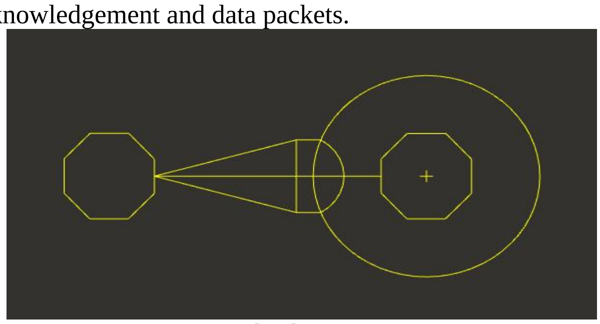


Figure 14 Directional and Isotropic antenna scenario

Scenario C:

In this scenario, PNC and peripheral devices both are using directional antennas for transmitting the packets.

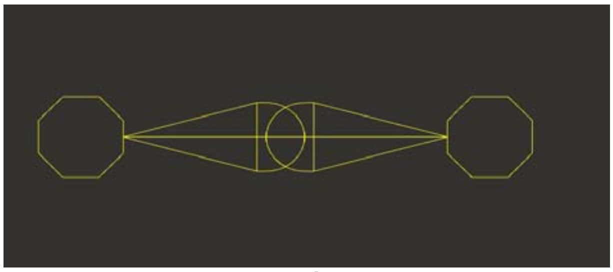


Figure 15 Directional antennas scenario

Scenario D (in cyan):

In this scenario Data is transmitted using the basic access method through transmitter antenna, which uses omni-directional pattern. The receiver operates in the directional mode.

In the above network model, PNC is surrounded by 6 peripheral devices and by referring figure 14 and15 for PNC and Device node model; the necessary changes can be made in antenna controller for testing the scenarios described above.

Collecting statistics and results

For this model, the effect different antenna patterns have on the throughput of a network is required. Instead of changing the antenna pattern attribute (which controls the antenna pattern used) at the node level for each simulation, the Simulation Sequence can be configured to vary this attribute automatically for parametric studies.

The radio transmitter/receiver channel statistics are going to be gathered for this simulation in the Project Editor. These statistics include **throughput** in bits/sec and end-to-end delay in seconds. The packet throughput statistic indicates the average number of packets the receiver channel successfully received per second. The end-to-end delay statistic indicates the total time taken for packet to travel from transmitter to receiver.An easy way to comply with the conference paper formatting requirements is to use this document as a template and simply type your text into it.

III. Results And Discussion

Throughput comparision

OPNET uses a **project** and **scenario** approach to model networks. **Project** is a collection of related network scenarios in which each explores a different aspect of network design. A **project** contains at least one scenario and a **scenario** is a single instance of a network containing all the information. It is possible to run all the scenarios of the network at the same time and compare the results of each one. This approach for modeling networks allows trying, the effect of modifying the models attribute, antenna pattern, which brings the changes in throughput and delay statistics which are being monitored in this case, etc.

Over here, the scenarios have been compared on the same graph so that it's easy to interpret the results. The various scenarios, which have been tested, are as below:

Scenario A (In Green):

In this scenario, all the nodes use omni-directional antennas for transmission and reception of packets.

Scenario B (in red):

In this scenario, directional antenna is used by PNC for sending the beacon and data packets, while peripheral devices are using omni-directional antennas for sending acknowledgement and data packets.

Scenario C (in Blue):

In this scenario, PNC and peripheral devices both are using directional antennas for transmitting the packets.

Scenario D (in cyan):

In this scenario Data is transmitted using the basic access method through transmitter antenna, which uses omni-directional pattern. The receiver operates in the directional mode.

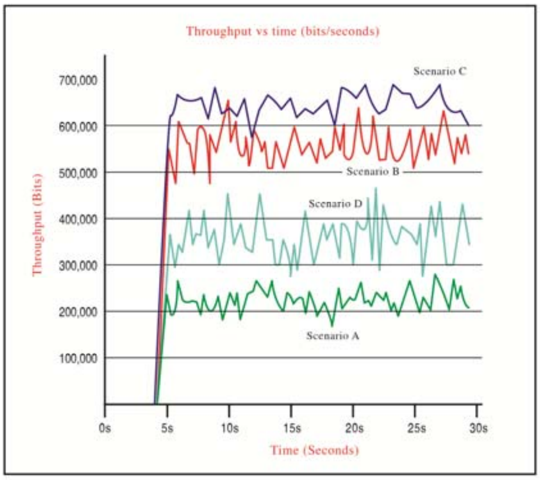


Figure 16 WPAN Throughput (bits/sec)

For the graph presented above for the network, four scenarios are generated, with the destination chosen randomly. Each scenario consists of 1000 packets or packet size of 850 kbits/sec. The bit rate of the network for the random scenarios is 1 Gb/s. Bandwidth of the wireless channel is kept at 2080 MHz and a frequency of 60 Gbps. Power of the transmitter module is .005 W. The throughput is computed as the total number of bits delivered successfully at the destination. In all cases, the throughput increases linearly with sustainable amount of traffic, and then degrades when overloaded due to the nature of contention based MAC protocols.

The main reason for the large throughput difference between scenario C and scenario A is due to the fact that the network is not as well connected when omni-directional antennas are used as with directional antennas (thanks to the longer links provided by directional neighbor discovery). Throughput increases with increasing directivity using directional antennas.

As seen in Figure 16, there is a performance improvement for scenarios involving use of directional antennas (scenario B). The performance gain is greatest for the method that uses directional antennas at PNC and DEV (scenario C).

In case of scenario C where PNC and DEV both uses directional antennas, maximum throughput is achieved as the nodes obtain all the necessary neighbor information from the antenna controller and so the packets are transmitted more efficiently and more accurately compared to scenario A where both the transmitter and receiver node is using omni-directional antennas.

There is a significant decrease in throughput for the scenarios using omni-directional pattern at transmitter and directional pattern at receiver as compared to the scenarios using directional pattern

End to end delay comparison

From figure 17 there are two curves, which are according to following scenarios

Scenario B (in Red):

In this scenario, directional antenna is used by PNC for sending the beacon and data packets, while peripheral devices are using omni-directional antennas for sending acknowledgement and data packets.

Scenario C (in Blue):

In this scenario, PNC and peripheral devices both are using directional antennas for transmitting the packets.

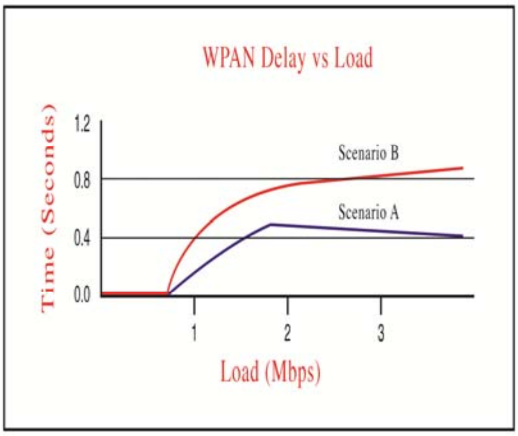


Figure 17 WPAN Delay (seconds)

Figure 17 shows the measurement of average end-to-end delay for data packets in mobile scenarios. As seen in Figure 17, the average packet delivery delay is smaller with the scenarios using directional antennas (curve in blue) at both the transmitter and receiver. This is due to the reason that transmitter calculates the information, which the antenna needs to point at a target: latitude, longitude, and altitude coordinates using pointing processor in case of directional antennas.

Whereas in case of scenarios using omni-directional antennas (curve in red), since the parameters are unknown, it takes time in finding the location of target devices and hence increase in end to end delay.

One more reason is that with devices using directional antennas, the link quality is much better compared with those using isotropic antennas and as a result the delay in transmitting the packets is done more efficiently and in lesser time for scenario in blue with directional antennas. Time taken is obviously more for scenarios using isotropic antennas due to poor link quality.

IV. CONCLUSIONS

In this paper, a model has been designed and implemented to monitor the performance of antennas in Gigabit WPAN's based on OPNET. The design of the model is such that different scenarios can be compared by just changing the attributes of antenna controller. A most general code has been generated in process model as far as possible; still it allows working efficiently with the monitoring of statistics and the OPNET simulator simultaneously.

On the other hand, OPNET seems to be a complete set of software that ensures that the results obtained are valid for a large set of problems.

Several problems emerging from the use of omni-directional antennas over directional antennas have been identified in case of Gigabit WPAN's. Performance evaluation suggests that using directional antennas are suitable for communication in case of wireless networks due to high throughput and comparatively less end-to-end delay.

For directional antenna scenarios, the evaluation and model have produced results that are encouraging, suggesting the need to use directional antennas more efficiently in this kind of networks, which will surely increase the Quality of service.

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