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Technical Report

The IEEE 802.15.4 OPNET Simulation Model: Reference Guide v2.0

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HURRAY-TR-070509
Version: 1.0
Date: 05-29-2007

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Abstract

This technical report provides a reference guide to the IEEE 802.15.4 OPNET simulation model. The simulation model can be used for the performance evaluation of the slotted CSMA/CA and GTS mechanisms in beacon enabled mode. The optimal setting of the protocol parameters can be found and verified with this simulation model.

Index

1. Overview of the IEEE 802.15.4 Protocol

The **IEEE 802.15.4** [1] protocol has recently been adopted as a communication standard for low data rate, low power consumption and low cost Wireless Sensor Networks (WSNs). This protocol is quite flexible for a wide range of applications by adequately tuning its parameters and it also provides real time guarantees by using the Guaranteed Time Slot (GTS) mechanism. This feature is quite attractive for time-sensitive WSN applications.

The IEEE 802.15.4 standard specifies the physical layer and MAC sub-layer for Low-Rate Wireless Personal Area Networks (LR-WPANs). The ZigBee [2] standard is close associated with the IEEE 802.15.4 protocol and specifies the network (including security services) and application (including objects and profiles) layers.

1.1. IEEE 802.15.4 Physical Layer

The physical layer is responsible for data transmission and reception using a certain radio channel according to a specific modulation and spreading techniques. The IEEE 802.15.4-2003 [1] standard offers three unlicensed frequency bands: 2.4 GHz (worldwide), 915 MHz (e.g. North America) and 866 MHz (e.g. Europe). There is a single channel between 868 and 868.6 MHz, 10 channels between 902 and 928 MHz and 16 channels between 2.4 and 2.483.5 GHz. The data rate is 250 kbps at 2.4 GHz, 40 kbps at 915 MHz and 20 kbps at 868 MHz. In addition to these three frequency band patterns, two high data rate patterns have been added to the 868/915 MHz bands in the last revision of the standard IEEE 802.15.4REVb-2006. The higher data rates are achieved by using of the different modulation formats. This revision of the standard is backward-compatible to the IEEE 802.15.4-2003, meaning that devices conforming to IEEE 802.15.4REVb-2006 are capable of joining and functioning in a PAN composed of devices conforming to IEEE 802.15.4-2003. All of these frequency bands are based on the Direct Sequence Spread Spectrum (DSSS) spreading technique.

PHY (MHz)	**Frequency Band (MHz)**	**Spreading Parameters**		**Data Parameters**		
		Chip rate (kchips/s)	Modulation	Bit rate (kb/s)	Symbol rate (ksymbol/s)	Symbols
868/915	868–868.6	300	BPSK	20	20	Binary
	902–928	600	BPSK	40	40	Binary
868/915 (optional)	868–868.6	400	ASK	250	12.5	20-bit PSSS
	902-928	1600	ASK	250	50	5-bit PSSS
868/915 (optional)	868–868.6	400	QPSK	100	25	16-ary Orthogonal
	902-928	1000	O-QPSK	250	62.5	16-ary Orthogonal
2450	2400–2483.5	2000	O-QPSK	250	62.5	16-ary Orthogonal

The protocol also allows dynamic channel selection, a scan function that steps through a list of supported channels in search of a beacon, receiver energy detection, link quality indication and channel switching.

1.2. IEEE 802.15.4 Medium Access Control Layer

The MAC protocol supports two operational modes that can be selected by a central controller of the Person Area Network (PAN), called PAN Coordinator:

- ***Beacon-enabled mode***: In beacon-enabled mode, the beacon frames are periodically generated by the PAN Coordinator to identify its PAN, to synchronize devices that are associated with it, and to describe the superframe structure.
- ***Non Beacon-enabled mode***: In non beacon-enabled mode, the device can simply send their data by using unslotted CSAM/CA mechanism. There is no use of a superframe structure in this mode. The advantages of this mode are a scalability and self-organization. However, the non beacon-enabled mode cannot provide any time guarantees to deliver data frames.

When the PAN Coordinator selects the beacon-enabled mode, it forces the use of a superframe structure to manage communication between the devices that are associated to that PAN. The format of the superframe is defined by the PAN Coordinator. The superframe, corresponding to the *Beacon Interval* (BI), is defined by the time between two consecutive beacons, and includes an active period and, optionally, a following inactive period. The active period, corresponding to the *Superframe Duration* (SD), is divided into 16 equally sized time slots, during which data transmission is allowed. Each active period can be further divided into a *Contention Access Period* (CAP) and an optional *Contention Free Period* (CFP). Slotted CSMA/CA is used within the CAP. The CFP is activated by the request sent from a device to the PAN Coordinator. Upon receiving this request, the PAN Coordinator checks whether there are sufficient resources and, if possible, allocates the requested time slots. This requested group of time slots is called *Guaranteed Time Slot* (GTS) and is dedicated exclusively to a given device. A CFP support up to 7 GTSs and each GTS may contain multiple time slots. The allocation of the GTS cannot reduce the length of the CAP to less than the value specified by *aMinCAPLength* constant.

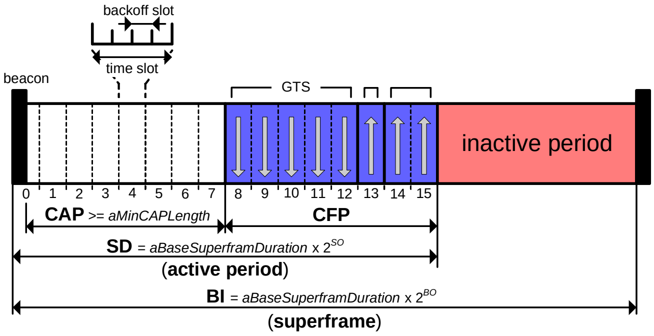


Figure 1. The IEEE 802.15.4 superframe structure

The *star* and *peer-to-peer* topologies are two basic network topologies defined in the IEEE 802.15.4 standard. In the star topology, the communication is centralized and established between a PAN Coordinator and its associated devices. The main advantage of this topology is its simplicity. The peer-to-peer topology has also a PAN Coordinator; however, it differs from the star topology in that any device can communicate with any other device within its radio range. The *cluster-tree* topology is a special case of a peer-to-peer topology with a distributed synchronization mechanism.

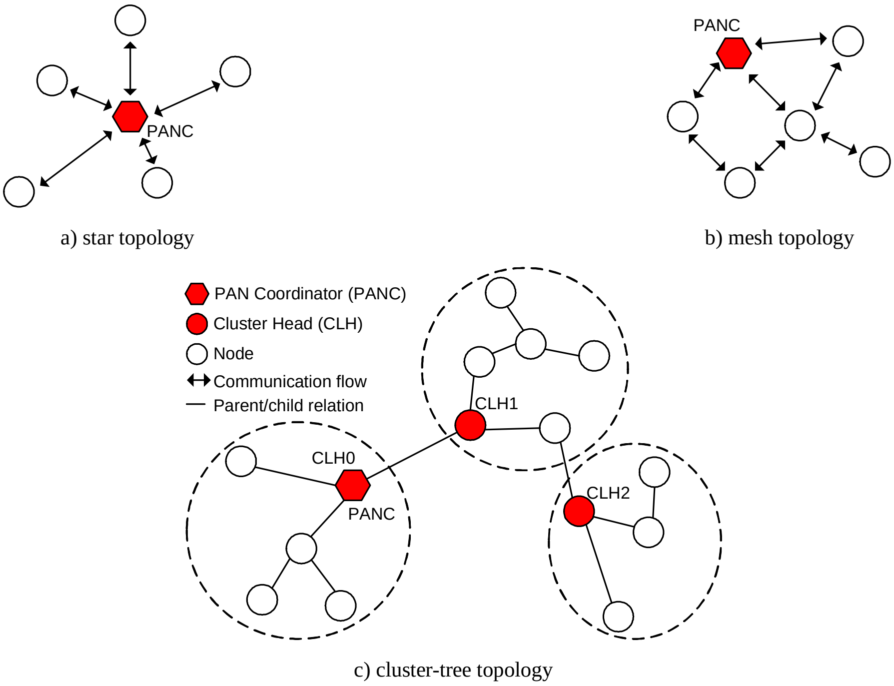


Figure 2. The IEEE 802.15.4 network topologies

2. The IEEE 802.15.4 Simulation Model

The simulation model implements physical and medium access control layers defined in the IEEE 802.15.4-2003 standard. The OPNET Modeler [3] is used for developing, namely due to its accuracy and to its sophisticated graphical user interface. The OPNET Modeler is an industry leading discrete-event network modeling and simulation environment. The wireless module extends the functionality of the OPNET Modeler with accurate modeling, simulation and analysis of wireless networks. This module is one of the several add-on modules available from OPNET.

The actual version of the simulation model only supports the **star topology** where the communication is established between devices, called inside the model *End Devices*, and a single central controller, called *PAN Coordinator*. Each device operates in the network must have a unique address.

The structure of the IEEE 802.15.4 sensor nodes (*wpan_sensor_node*) used in the simulation model is composed of four functional blocks:

1. The **Physical Layer** consists of a wireless radio transmitter (***tx***) and receiver (***rx***) compliant to the IEEE 802.15.4 specification, operating at the 2.4 GHz frequency band and a data rate equal to 250 kbps. The transmission power is set to 1 mW and the modulation technique is Quadrature Phase Shift Keying (QPSK).
2. The **MAC Layer** implements the slotted CSMA/CA and GTS mechanisms. The GTS data traffic (i.e. time-critical traffic) incoming from the application layer is stored in a buffer with a specified capacity and dispatched to the network when the corresponding GTS is active. The non time-critical data frames are stored in an unbounded buffer and based on the slotted CSMA/CA algorithm are transmitted to the network during the active CAP. This layer is also responsible for generating beacon frames and synchronizing the network when a given node acts as PAN Coordinator.
3. The **Application Layer** consists of two data traffic generators (i.e. *Traffic Source* and *GTS Traffic Source*) and one *Traffic Sink*. The Traffic Source generates unacknowledged and acknowledged data frames transmitted during the CAP (uses slotted CSMA/CA). The GTS Traffic Source can produce unacknowledged or acknowledged time-critical data frames using the GTS mechanism. The Traffic Sink module receives frames forwarded from lower layers and performs the network statistics.
4. The **Battery Module** computes the consumed and the remaining energy levels. The default values of the current draws are set to those of the MICAz mote specification [4].

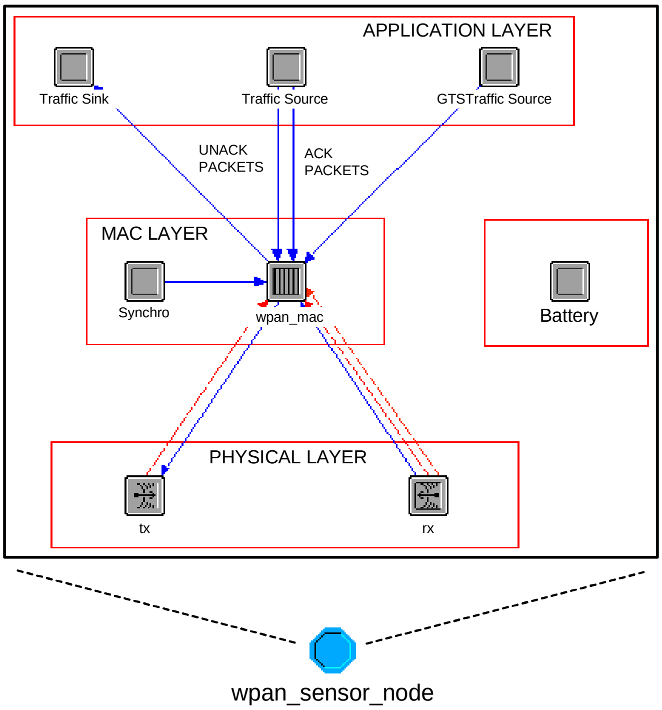


Figure 3. The structure of the IEEE 802.15.4 Simulation Model

The actual version of the simulation model is 2.0 and is not backward-compatible to the previous version 1.0, meaning that the devices conforming to version 1.0 are not capable of joining and functioning in a PAN composed of devices conforming to version 2.0 and vice-versa.

The actual version 2.0 of the simulation model implements the following functions in accordance with the IEEE 802.15.4-2003 standard.

Support (implemented) features:

- Beacon-enabled mode
- Slotted CSMA/CA MAC protocol
- Frame formats (beacon, command, ack, mac_packet)
- Physical layer characteristics
- Computation of the power consumption (MICAz and TelosB (TmoteSky) motes supported) - Battery Module
- Guaranteed Time Slot (GTS) mechanism (GTS allocation, deallocation and reallocation functions)
- Generation of the acknowledged and unacknowledged application data (MAC Frame payload = MSDU) transmitted during the Contention Access period (CAP)
- Generation of the acknowledged or unacknowledged application data transmitted during the Contention Free Period (CFP)

Non-support features:

- Non beacon-enabled mode
- Unslotted CSMA/CA MAC protocol
- PAN management (association/disassociation)
- ZigBee Network Layer

The values of all constants and variables in this simulation model are considered for the 2.4 GHz frequency band with a data rate of 250 kbps, which is supported by the MICAz or TelosB motes, for example. In this case, one symbol corresponds to 4 bits. For other frequency bands and data rates it is necessary to change appropriate parameters inside the simulation model (e.g. the header file *wpan_params.h*).

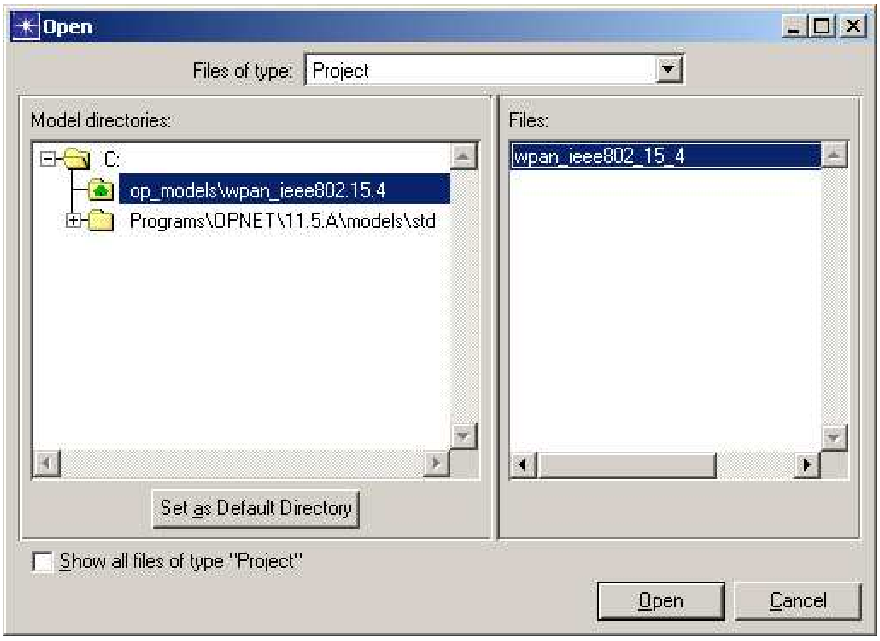
There are two types of nodes inside the simulation model:

- ***wpan_analyzer_node***: This node captures global statistical data from whole PAN (one within PAN).
- ***wpan_sensor_node***: This node implements the IEEE 802.15.4-2003 standard as was mentioned above.

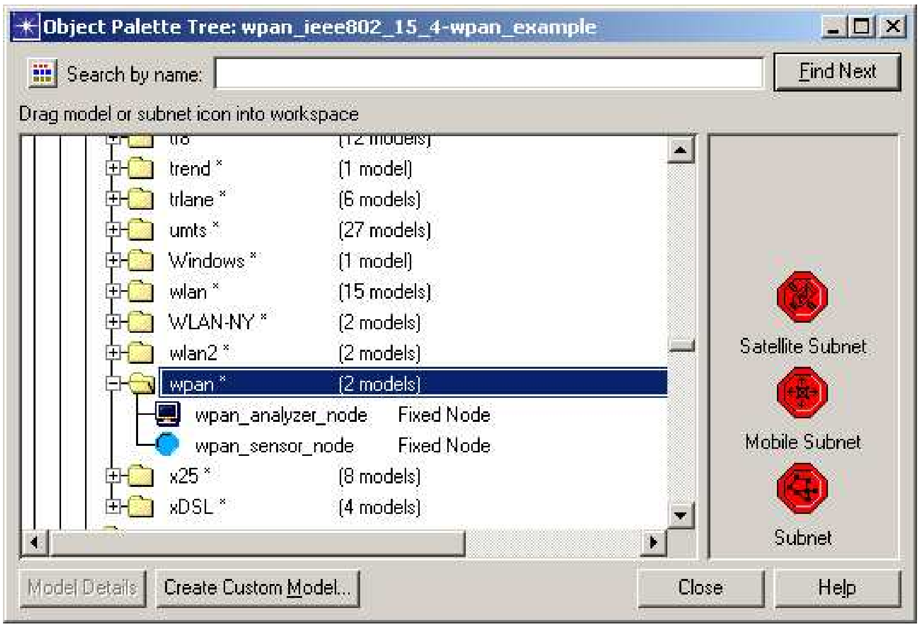
3. Installation of the Simulation Model

The IEEE 802.15.4 OPNET simulation model can be downloaded from the Open-ZB web page [5]. The simulation model was developed and tested under the OPNET Modeler Wireless Suite [3] version 11.5.A provided under the OPNET University Program license, where Wireless Suite extends Modeler with the wireless libraries (e.g. radio transmitter and receiver). To install and run IEEE 802.15.4 OPNET Simulation Model in your computer, follow these steps (for OPNET Modeler version 11.5):

1. Unzip downloaded file to any user-defined directory.
2. Add this directory to the OPNET Model directories: *File → Model Files → Add Model Directory*. The name of directory is automatically added to the environment database file: op_admin\env_db11.5.
3. After that, the directory name can be found in the Open file dialog: *File → Open*. Select appropriate Model Directory and File and press **Open**.



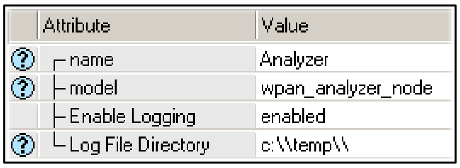
4. The default OPNET scenario contains one analyzer node (*wpan_analyzer_node*) and three sensor nodes (*wpan_sensor_node*). Additional nodes can be added from the model repository:
   Topology → Open Object Palette → Node Models → Fixed Node Models → By Name → wpan.



4. User-defined Attributes

1.3. wpan_analyzer_node

This node captures global statistical data from whole PAN (only one node within PAN). The hierarchical structure of the user-defined attributes of the *wpan_analyzer_node* node model follows.



Attribute	Value
name	Analyzer
model	wpan_analyzer_node
Enable Logging	enabled
Log File Directory	c:\\temp\\

Figure 4. The user-defined attributes of the *wpan_analyzer_node* node

Logging

- Enable Logging *[disable]*
- Log File Directory *[c:\]*

Logging

The output to the text file and on the screen can be allowed by these parameters.

Attribute Name	Value	Description
Enable Logging	[enabled/ disabled]	Enable the storing of the output to the file and show on the screen.
Log File Directory		The valid directory path for storing an appropriate log file if a logging is enabled.

1.4. wpan_sensor_node

This node implements the IEEE 802.15.4 standard as was in Section 1.The hierarchical structure of the user-defined attributes of the *wpan_sensor_node* node model follows. Default values of the attributes are in the brackets and written in italic. Attributes marked with a filled square (■) are valid only for the PAN Coordinator (a node with the device mode attribute equal to PAN Coordinator). Attributes marked with a diamond (♦) are valid only for the End Device.

Attribute	Value
name	node_1
model	wpan_sensor_node
⊟ Traffic Source	
⊞ Acknowledged Traffic Parameters	(...)
Destination MAC Address	Broadcast
⊞ Unacknowledged Traffic Parameters	(...)
⊟ CSMA/CA Parameters	(...)
Maximum Backoff Number	4
Minimum Backoff Exponent	3
⊟ Battery	
⊞ Current Draw	(...)
Initial Energy	2 AA Batteries (3V, 1600 mAH)
Power Supply	2 AA Batteries (3V)
⊟ IEEE 802-15-4	
Device Mode	End Devcie
MAC Address	Auto Assigned
⊞ MAC Attributes	(...)
⊞ WPAN Setting	(...)
⊞ Logging	
⊟ GTS	
⊞ GTS Setting	(...)
⊞ GTS Traffic Parameters	(...)

Figure 5. The user-defined attributes of the *wpan_sensor_node* node

Traffic Source

- Acknowledged Traffic Parameters
  - MSDU Interarrival Time *[constant(1.0)]*
  - MSDU Size *[constant(0.0)]*
  - Start Time *[Infinity]*
  - Stop Time *[Infinity]*
- Unacknowledged Traffic Parameters
  - MSDU Interarrival Time *[constant(1.0)]*
  - MSDU Size *[constant(0.0)]*
  - Start Time *[Infinity]*
  - Stop Time *[Infinity]*
- Destination MAC Address *[Broadcast]*

CSMA/CA Parameters

- Maximum Backoff Number *[4]*
- Minimum Backoff Exponent *[3]*

Battery

- Current Draw
  - Receive Mode *[MICAz]*
  - Transmission Mode *[MICAz (0 dBm)]*
  - Idle Mode *[MICAz]*
  - Sleep Mode *[MICAz]*
- Initial Energy *[2 AA Batteries (1.5V, 1600 mAH)]*
- Power Supply *[2 AA Batteries (3V)]*

IEEE 802-15-4

- Device Mode *[End Device]*
- MAC Address *[Auto Assigned]*
- MAC Attributes
  - Battery Life Extension ■ *[disabled]*
- WPAN Setting
  - Beacon Order ■ *[15]*
  - Superframe Order ■ *[15]*
  - PAN ID ■ *[0]*

Logging
- Enable Logging *[disable]*
- Log File Directory *[c:\]*

GTS
- GTS Setting
  - GTS Permit ■ *[enabled]*
  - Start Time ♦ *[Infinity]*
  - Stop Time ♦ *[Infinity]*
  - Length ♦ *[0]*
  - Direction ♦ *[transmit]*
  - Buffer Capacity ♦ *[1000]*
- GTS Traffic Parameters
  - MSDU Interarrival Time ♦ *[constant(1.0)]*
  - MSDU Size ♦ *[constant(0.0)]*
  - Acknowledgement ♦ *[disabled]*

Traffic Source

The Traffic Source module generates unacknowledged and acknowledged application data. These application data can be generated by the PAN Coordinator or by the End Device, and are transmitted as a MAC Frame Payload (i.e. MAC Service Data Unit (MSDU)) during the Contention Access Period (CAP). The parameters for acknowledged (Acknowledged Traffic Parameters) and unacknowledged (Unacknowledged Traffic Parameters) data can be individually setting. During the period, which is bounded by the ***Start Time*** and ***Stop Time*** attributes, the acknowledged and/or unacknowledged application data are generated independently from each other. The size of the generated MSDU is specified by the probability distribution function of the ***MSDU Size*** attribute. The probability distribution function, specified in the ***MSDU Interarrival Time*** attribute, defines the inter-arrival time between two consecutive MSDUs. Then, the MSDU is wrapped in the MAC header and stored as a frame in the buffer. The default size of the MAC header (*MAC_HEADER_SIZE*) is 104 bits, since only 16-bit short addresses are used for communication (according to standard specification). The maximum allowed size of the overall frame (i.e. MSDU plus the MAC header) is equal to *aMaxPHYPacketSize* (1016 bits). When the CAP is active, the frames are removed from the buffer, wrapped in the PHY header and dispatched to the device with a given ***Destination MAC Address***.

If the *Destination MAC Address* attribute is set to *Broadcast*, the acknowledged traffic will not be generated regardless the *Acknowledged Traffic Parameters*. *Stop Time* must be later than *Start Time* otherwise data traffic will not be generated.

- **Acknowledged Traffic Parameters**
- **Unacknowledged Traffic Parameters**

Attribute Name	Value	Description
MSDU Interarrival Time	PDF* [sec]	The inter-arrival time in seconds between two consecutive MSDUs.
MSDU Size	PDF [bits]	The size in bits of the generated data unit i.e. MSDU. The value can be from the interval (0, *aMaxMACFrameSize*). The values out of this interval are automatically set to boundary values. *aMaxMACFrameSize* is the maximum size that can be transmitted as a MAC Frame Payload and is equal to *aMaxPHYPacketSize - MAC_HEADER_SIZE* (i.e. 1016 - 104 = 912 bits).
Start Time	[sec]	The absolute simulation time in seconds when the traffic source will start its data generation. Setting the value to *Infinity* will simply disable the source.
Stop Time	[sec]	The absolute simulation time in seconds when the traffic source will stop its traffic generation. Setting the value to *Infinity* will make the traffic source generate data until the end of the simulation.

* Probabilistic Distribution Function

Attribute Name	Value	Description
Destination MAC Address		The generated data traffic will be transmitted to the device with this short (16-bit) address. The valid address has to be assigned to the destination device (*MAC Address* attribute). There are 2 predefined addresses: • **PAN Coordinator**: address of the actual PAN Coordinator • **Broadcast**: broadcast short address (0xFFFF), which shall be accepted as a valid short address by all devices inside the PAN.

CSMA/CA

The parameters related to the slotted CSMA/CA mechanism. The slotted CSMA/CA mechanism is used in beacon-enabled mode during the CAP. The slotted CSMA/CA algorithm is based on backoff slots, where one backoff slot is equal to *aUnitBackoffPeriod* (20 Symbols). This is the basic time unit of the MAC protocol and the access to the channel can only occur at the boundary of the backoff slots. The backoff slot boundaries must be aligned with the superframe slot boundaries. Each time a device wishes to transmit frames during the CAP, it shall locate the boundary of the next backoff slot and then wait for a random number of backoff slots. If the channel is busy, following this random backoff, the device shall wait for another random number of backoff slots before trying to access the channel again (this can be repeated ***Maximum Backoff Number*** times). If the channel is idle, the device can begin transmitting on the next available backoff slot boundary.

Attribute Name	Value	MAC PIB* variable	Description
Maximum Backoff Number	0-5	*macMaxCSMABackoffs*	The maximum number of retries (backoffs) the CSMA/CA algorithm will attempt before the algorithm terminates with a channel access failure status.
Minimum Backoff Exponent	0-3	*macMinBE*	The minimum value of the backoff exponent (*BE*) in CSMA/CA algorithm. Backoff exponent is related to how many backoff periods a device must wait before attempting to assess the channel activity.

* MAC PAN Information Base

Battery

The Battery module computes the consumed and the remaining energy levels during the active and inactive periods. The default values of the current draws are set to those of the MICAz mote specification [4].

- **Current Draw** - the current draw in different modes

Attribute Name	Value	Description
Receive Mode	[mA]	The current draw of the device when the transceiver is in the receiving mode (RX_ON state). There are 2 predefined options default for MICAz and TelosB motes: • **MICAz** = 27.7 mA • **TelosB** = 24.8 mA
Transmission Mode	[mA]	The current draw of the device when the transceiver is in the transmitting mode (TX_ON state). There are 6 predefined options corresponding to the nominal transmitting power of the transceiver: • **MICAz (0 dBm)** = **TelosB (0 dBm)** = 17.4 mA • **MICAz (-5 dBm)** = **TelosB (-5 dBm)** = 14 mA • **MICAz (-10 dBm)** = **TelosB (-10 dBm)** = 11 mA
Idle Mode	[µA]	The current draw of the device when the transceiver is in idle mode and voltage regulator is on. There are 2 predefined options default for MICAz and TelosB motes: • **MICAz** = 35 µA • **TelosB** = 26.1 µA
Sleep Mode	[µA]	The current draw of the device when the transceiver is inactive and voltage regulator is off. There are 2 predefined options default for MICAz and TelosB motes: • **MICAz** = 16 µA • **TelosB** = 6.1 µA

Attribute Name	Value	Description
Initial Energy	[Joule=Ws]	The initial amount of battery energy before any activity. The relation between battery voltage (U[V]), battery capacity (C[mAh]) and energy (E[Joule]): $E = U[\text{V}] \times C[\text{mAh}] = [\text{Watt} \times \text{sec}] = [\text{Joule}]$ There are 3 predefined types of batteries with the following initial energies: • **2 AA Batteries (1.5V, 2300 mAh)** = 2 × 24 840 = 49 680 Joule • **2 AA Batteries (1.5V, 1600 mAh)** = 2 × 17 280 = 34 560 Joule • **2 AA Batteries (1.5V, 1200 mAh)** = 2 × 12 960 = 25 920 Joule
Power Supply	[V]	The battery voltage in Volts. There is 1 predefined option: • **2 AA Batteries (3V)** = 3 Volts (each battery with voltage 1.5V)

IEEE 802-15-4

In beacon-enabled mode, beacons frames are periodically sent by the PAN Coordinator to identify its PAN, to synchronize devices that are associated with it and to describe the structure of the superframe. The superframe, corresponding to the *Beacon Interval* (*BI*), is defined by the time between two consecutive beacons, and includes an active period and, optionally, a following inactive period. The active period, corresponding to the *Superframe Duration* (*SD*), is divided into 16 equally sized time slots, during which data transmission is allowed. During the optional inactive period, each device may enter a low power mode to save energy resources.

The structure of the superframe is defined by two parameters, the ***Beacon Order*** (*BO*) and the ***Superframe Order*** (*SO*), which determine the length of the superframe and its active period. The setting of *BO* and *SO* must satisfy the relationship $0 \le SO \le BO \le 14$. The length of the superframe (BI) and the length of its active period (SD) are then defined as follows:

$$BI = aBaseSuperframeDuration \times 2^{BO},$$

$$SD = aBaseSuperframeDuration \times 2^{SO}.$$

The *aBaseSuperframeDuration* constant denotes the minimum length of the superframe when *BO* is equal to 0. The IEEE 802.15.4 standard fixes this duration to 960 symbols.

If $SO = BO$ then $SD = BI$ and the superframe is always active. According to the standard, if $SO = 15$, the superframe will not be active following the beacon. Moreover, if $BO = 15$, then the superframe shall not exist and the network will operate in the non beacon-enabled mode. In this case, the value of *SO* is ignored. As a result, a PAN that wishes to use the superframe structure must set Beacon Order to a value between 0 and 14 and Superframe Order to a value between 0 and the value of Beacon Order.

Each independent PAN selects a unique identifier. This PAN identifier (***PAN ID***) allows communication between devices within a network using short addresses and enables transmissions between devices across independent networks. Thus, all networks can operate independently from all others currently in operation.

The actual version of the simulation model only supports the star topology where the communication is established between devices, called inside the model *End Devices*, and a single central controller, called *PAN Coordinator* (***Device Mode*** attribute). Each device operates in the network must have a unique address (***MAC Address*** attribute).

● **WPAN Setting** - the following attributes are related only to the PAN Coordinator. The End Devices receives these values in the beacon frame.

Attribute Name	Value	MAC PIB variable	Description
Beacon Order ■	[0-15]	*macBeaconOrder*	Specification of how often the PAN coordinator transmits a beacon frame (i.e. Beacon Interval *BI*). If Beacon Order is equal to 15, the PAN coordinator will not transmit a beacon (i.e. non beacon-enabled mode).
Superframe Order ■	[0-15]	*macSuperframeOrder*	The length of the active portion of the superframe, including the beacon frame. If Superframe Order is equal to 15, the superframe will not be active following the beacon.
PAN ID ■	Integer	*macPANId*	Identification of the network where the PAN Coordinator is active.

Attribute Name	Value	MAC PIB variable	Description
Device Mode	[End Device/ PAN Coordinator]		The function of the device within network (PAN). The device can act as a PAN Coordinator or an End Device. • **PAN Coordinator**: There can be only one PAN Coordinator within PAN providing synchronization through the beacon transmission. • **End Device**: A device associated and synchronized with the PAN Coordinator.
MAC Address		*macShortAddress*	The unique short (16-bit) address of the device using for the communication within PAN. There is 1 predefined option: • **Auto Assigned** = device address will be randomly generated

● **MAC Attributes**

Attribute Name	Value	MAC PIB variable	Description
Battery Life Extension ■	[enabled/ disabled]	*macBattLifeExt*	The initial value of the Backoff Exponent (BE) is equal to min(2, *macMinBE*) if the Battery Life Extension is enabled or BE is equal to *macMinBE* if it is disabled.

Logging

The output to the text file and on the screen can be allowed by this setting.

Attribute Name	Value	Description
Enable Logging	[enabled/ disabled]	Enable the storing of the output to the file.
Log File Directory		The valid directory path for storing an appropriate log file if a logging is enabled.

GTS

Each active period can be further divided into a Contention Access Period (CAP) and an optional Contention Free Period (CFP). The CFP is activated by the request sent from an End Device to the PAN Coordinator and provides real-time guarantees for time-critical data. Upon receiving this request, the PAN Coordinator checks whether there are sufficient resources and, if possible, allocates the requested time slots. This requested group of time slots is called Guaranteed Time Slot (GTS) and is dedicated exclusively to a given device. A CFP support up to 7 GTSs and each GTS may contain multiple time slots. The GTS allows the corresponding device to directly access the medium without contention with other devices inside the PAN. A GTS can only be allocated by the PAN coordinator and applied exclusively to data transfer between the device and its coordinator, either from the End Device to the PAN Coordinator (transmit direction) or from the PAN Coordinator to the End Device (receive direction). Each device may request one GTS in the transmit direction and/or one GTS in the receive direction. The allocation of the GTS cannot reduce the length of the CAP to less than *aMinCAPLength* (440 symbols). If the available resources are not sufficient, the GTS allocation is denied by the PAN Coordinator. End Device to which a GTS has been allocated can also transmit during the CAP.

The PAN Coordinator may accept or reject the GTS allocation request from the End Device according to the value of the user defined attribute ***GTS Permit***. The End Device can specify the time when the GTS allocation and deallocation requests are sent to the PAN Coordinator (***Start Time*** and ***Stop Time*** attributes). This allocation request also includes the number of required time slots (***GTS Length*** attribute) and their direction, transmit or receive (***GTS Direction*** attribute).

When the requested GTS is assigned to a given device, its application layer starts generating data blocks that correspond to the MAC frame payload (i.e. MAC Service Data Unit (MSDU)). The size of the frame payload is specified by the probability distribution function of the ***MSDU Size*** attribute. The probability distribution function, specified in the ***MSDU Interarrival Time*** attribute, defines the inter-arrival time between two consecutive frame payloads. Then, the frame payload is wrapped in the MAC header and stored as a frame in the buffer with a given capacity (***Buffer Capacity*** attribute). The default size of the MAC header (*MAC_HEADER_SIZE*) is 104 bits, since only 16-bit short addresses are used for communication (according to standard specification). The maximum allowed size of the overall frame (i.e. frame payload plus the MAC header) is equal to *aMaxPHYPacketSize* (1016 bits). The generated frames exceeding the buffer capacity are dropped. When the requested GTS is active, the frames are removed from the buffer, wrapped in the PHY headers and dispatched to the network with an outgoing data rate equal to physical data rate *WPAN_DATA_RATE* (250 kbps).

● **GTS Setting**

Attribute Name	Value	MAC PIB variable	Description
GTS Permit ■	[enabled/ disabled]	*macGTSPermit*	Enabled if the PAN Coordinator accepts GTS request from End Device. Disabled otherwise.
Start Time ♦	[sec]		The absolute simulation time in seconds when the application layer will start its GTS data generation. Setting the value to *Infinity* will simply disable data generation.
Stop Time ♦	[sec]		The absolute simulation time in seconds when the application layer will stop its GTS data generation. Setting the value to *Infinity* will make the application layer generate GTS data until the end of the simulation.
Length ♦	0-15 slots		The length of the GTS in superframe slots within one superframe.
Direction ♦	[transmit/ receive]		The direction of the transmission from the End Device point of view: • **transmit**: End Device → PAN Coordinator • **receive**: End Device ← PAN Coordinator
Buffer Capacity ♦	[bits]		The capacity of the FIFO buffer for storing the traffic arriving from the application layer before dispatching to the network.

● **GTS Traffic Parameters** - generation of the GTS application data traffic

Attribute Name	Value	Description
MSDU Interarrival Time ♦	PDF* [sec]	The inter-arrival time in seconds between two consecutive MSDUs.
MSDU Size ♦	PDF [bits]	The size in bits of the generated data unit i.e. MSDU. The value can be from the interval (0, *aMaxMACFrameSize*). The values out of this interval are automatically set to boundary values. *aMaxMACFrameSize* is the maximum size that can be transmitted in the MAC Frame Payload and is equal to *aMaxPHYPacketSize - MAC_HEADER_SIZE* (i.e. 1016 - 104 = 912 bits)
Acknowledgement ♦	[disabled/ enabled]	Enable if the generated data should be acknowledged.

* PDF = Probabilistic Distribution Function

References

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