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Editorial Preface

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The Design of a Simulation for the Modeling and Analysis of Public Transportation Systems as Opportunistic Networks

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Abstract

Vehicular ad-hoc networks, when combined with wireless sensor networks, are used in a variety of solutions for commercial, urban, and metropolitan areas, including emergency response, traffic, and environmental monitoring. In this work, we model buses in the Washington, DC Metropolitan Area Transit Authority (WMATA) as a network of vehicular nodes equipped with wireless sensors. A simulation tool was developed, to determine performance metrics such as end-to-end packet delivery delay.

Keywords: Opportunistic networks, Vehicular networks, Simulation, Network simulation

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1. INTRODUCTION

Mobile ad hoc networks (MANET) have provided technological connectivity in areas where various constraints, including environmental, financial, cultural, time, and government prohibited the establishment of infrastructure-based networks. Nodes may be static or mobile, leading to a dynamic network topology. Routing of data occurs as nodes relay information to each other. Traditional ad hoc routing protocols assume the network is fully connected. In addition, the end-to-end source-destination path is assumed to be known prior to transmission.

The need for increased connectivity extends from urbanized areas to remote and rural areas previously unreachable via standard telecommunication networks. In either of these cases, the establishment or use of an infrastructure-based network is not always feasible, due to various constraints, including time, financial, cultural, government, and environmental. In addition, certain catastrophic events can render infrastructure networks useless.

Opportunistic or disruption tolerant networks (DTN) are special types of MANETs where no end-to-end path exists between source and destination nodes, due to a number of potential factors, including node mobility, physical obstructions, etc. Packet transmission occurs in a store-and-forward fashion, where nodes relay packets to neighboring nodes as they come in contact with each other, until the packet ultimately reaches its destination. As a result, packets must endure longer delays.

Vehicular ad-hoc networks (VANETs) are a special type MANET where cars or buses are equipped with devices that allow them to communicate with each other and any stationary equipment they may pass. These vehicles, referred to as nodes, are restricted to movement on streets or designated paths. In a major metropolitan area, public transportation systems can be utilized to provide opportunistic routing and delivery of data via buses. When equipped with wireless sensors, these networks can be used for a number of purposes, including health, environmental, habitat, and traffic monitoring, emergency response, and disaster relief [4, 10, 11, 15, 16, 20, 22].

In this work, we develop a simulation tool for modeling and analyzing a DTN comprised of buses in a public transportation system. Using real bus information and schedules, the simulation provides a realistic model of the entire network. This tool can be used to study various routing protocols and network performance metrics, such as end-to-end packet delay, packet copy distribution, and more. In addition, we provide a web-based front-end, using the Google Maps API, that provides a user-friendly interface for updating the network to account for a number of parameters and conditions, including inclement weather, traffic congestion, and other adverse conditions.

We note that, while this work uses the Washington Metropolitan Area Transit Authority (WMATA) system, the simulation can model any public transportation system that subscribes to the defined specification. It is the ultimate goal that this simulation will be used not only to study the use of the public transportation systems of cities for various societal and research purposes, but also to provide a means for any organization or individual to utilize this tool to gather relevant data.

The remainder of this work is organized as follows. In section 2, we discuss related work on DTN simulation models. In section 3, we present the network model. In section 4, we present the simulation model and web-based front end. In section 5, we present numerical results and a snapshot of our simulation application. In section 6, we conclude our findings.

2. RELATED WORK

Opportunistic or delay tolerant networks (DTN) have been suggested as a viable solution for a number of non-traditional mobile ad-hoc networks. These include providing connectivity in rural or remote areas, wildlife tracking and monitoring, and military battlefields, to name a few. A large majority of the work has focused on the development and analysis of routing protocols to measure a number of performance metrics, including end-to-end delay and packet copy distribution.

Recently, work in the area of DTN has shifted to include urban environments and the capabilities in these areas [2, 8, 10, 15, 19, 23]. Specifically, the use of vehicular nodes has been studied. These networks are assumed to perform a number of tasks, including traffic and environment monitoring, and emergency response, and disaster recovery. A large amount of work has focused on various routing strategies for these networks [1, 2, 3, 5, 7, 9, 11, 15, 16, 17, 18].

In these networks, there are a number of attempts to model various protocols using testbeds [12, 13, 14, 15, 23]. These testbeds range from small networks of robots emulating the movement of vehicles to actual buses equipped with processing capabilities. In each of these cases, there are limitations to the implementation. Mainly, the size of the actual networks can make the creation of an exact replica extremely difficult, if not impossible. Second, the implementation of these studies on the actual network can be difficult to implement, due to financial, regulatory, and time constraints.

Simulations are a viable solution to modeling and analyzing opportunistic networks exploiting vehicular nodes in urban areas [15, 16, 19]. These networks can be analyzed, in full, prior to implementation. The benefit in this research is the ability to study the performance of the network using a number of protocols and parameters. While these are easier to implement than physical testbeds, creating such a large-scale simulation, that incorporates a large number of nodes and data movement can quickly become complex. This requires adequate emulation of vehicular movement, data transmission, schedules, and more.

To the best of our knowledge, there is still much open research in the area of simulations of DTN in urban environments. Specifically, the use of public transportation (i.e. buses, subway, etc.) as vehicular nodes has only recently begun to receive attention. The complexity of such networks, due to the aforementioned schedules, number of nodes, etc. can make this type of network difficult to accurately simulate.

In addition, the aforementioned simulations are designed to address a specific network representation. Our simulation allows for various public transportation networks to be studied using the Google Transit Feed Specification. Simulation parameters do not require modification when studying various cities.

Our research focuses on developing a simulation tool that can be used to study DTN in urban environments exploiting the public bus system of any city. The novelty of our research is the development of a tool that can be used to study various protocols and metrics of interest by providing a common format for modeling any city, using a Google-developed specification for transit data. While simulations have been developed, to the best of our knowledge, our work is the first that incorporates real data, including schedules, sing Google Transit Feed Specification. The benefit of using this that the tool can be used to study any city whose public transportation information is provided via the specification. Furthermore, the web-based front-end provides a simplified mechanism for manipulating and executing the simulation.

3. NETWORK MODEL

The network is composed of all streets that comprise the WMATA public transportation grid, including Washington, DC-proper and adjacent cities in both Maryland and Virginia. A node in the network is represented by a bus. Each station and node is assumed to be equipped with processing capabilities and a small buffer. Each bus belongs to a bus (node) line, which has a pre-determined path comprised of a set of streets. We note that a single line contains multiple buses traveling in opposite directions, referred to as upstream and downstream. In addition, every bus on every line has an expected arrival/departure time to/from each designated stop along the line.

A stop is defined as a stationary bus stop or base station, where data collection/dissemination activities take place. We assume each stop is equipped with the necessary equipment (e.g. sensors, etc.) to collect and store data. At any stop, a packet is randomly generated that is destined for another stop. The packet is transmitted to the first node that reaches the stop after this generation. As the carrier node travels throughout the network, it transmits the packet to any node it encounters that is within transmission range. A packet is delivered once it reaches the destination stop.

In this work, we make the following assumptions:

- Packets are originated at and delivered to stops in the network. Buses (nodes) serve as intermediate carriers for relaying information from a source (stop) to destination (stop).
- A packet can be transmitted to a node or line that previously carried the packet.
- If two nodes are within communication range of the current carrier node, then the new carrier is randomly selected.
- At the end of the last bus route, buses store all packets in their respective buffers until the next day's routes begin.
- Packets arriving to nodes with full buffers are undeliverable. However, the transmitting node retains copies of the packets.

4. SIMULATION MODEL

To test our simulation, we used actual bus information from the Washington Metropolitan Area Transit Authority (WMATA). This information includes a total of approximately 1,400 buses on 350 different bus lines over approximately 80 sq. miles. We note that each bus line contains more than one bus in each direction.

In order to accurately and efficiently obtain and analyze real WMATA information, we used the General Transit Feed Specification (GTFS). GTFS is a Google-defined specification that provides a common format for mapping a city's public transportation with its associated geographic info using the Google Maps API [6, 21]. Using GTFS, the public transportation agency of any city can prepare a data feed according to specifications, validate it, and enroll in a partnership with the Google Transit team to launch the feed in GTFS. Submitted feed information includes subway, bus, and train info. The associated data is then displayed in Google Maps. Information provided via GTFS includes parameters such as station/stop name, longitude, latitude, bus/subway stops and lines, etc. A number of public transportation agencies across the country and globe currently have feeds in GTFS, including major metropolitan areas such as San Francisco, Boston, Philadelphia, Washington, DC, and New York.

Using a custom, Java-based discrete-event simulator, we model and simulate the movement of buses and data in the network. We use GTFS, JavaScript, XML, and the Google Maps API to build a custom, web-based front-end for our simulation. This front-end was developed to provide an alternative view of the simulation results. Users can not only view the resulting path that a delivered packet traverses, but also manipulate specific input parameters, such as number of network packets, start time, source-destination pairs, and adverse conditions (inclement weather, accidents, etc.) within a user-friendly environment. The front-end was developed with the goal of providing various agencies and authorities studying the use of public transportation for various research or application purposes could use the simulation, combined with the corresponding GTFS feed for a specific city, and easily manipulate the simulation, regardless of their level of knowledge regarding the simulation design and implementation.I

Using the information provided by GTFS and our discrete-event simulator, packets are randomly generated at stops, and transferred by nodes to destination stops. Each node has a small buffer that allows for the storing of packets in transit. The exchange of a data packet occurs when two nodes are within 500 ft. of each other.

5. NUMERICAL RESULTS

In this work, we simulate a seven-day time period in the WMATA. Packets are randomly generated throughout the network at various sources and at various times of day. In addition, we assume that packets are routed according to flooding. At the end of each day, all buses with packets in their respective buffers store these packets until the next morning's route begins. For our work, we use a maximum node buffer size of 12 packets and a maximum number of 10 unique packets destined for different source-destination packets in the network. We note that, while 10 unique packets are generated, there are multiple copies of these 10 packets present throughout the network.

Figure 1 presents a snapshot of the current web-based front-end. It should be noted that, in addition to being able to map the resulting path traversed, the simulation also allows users to input a number of parameters to manipulate the simulation, including weather conditions, rush hour starting time, packet size, etc.

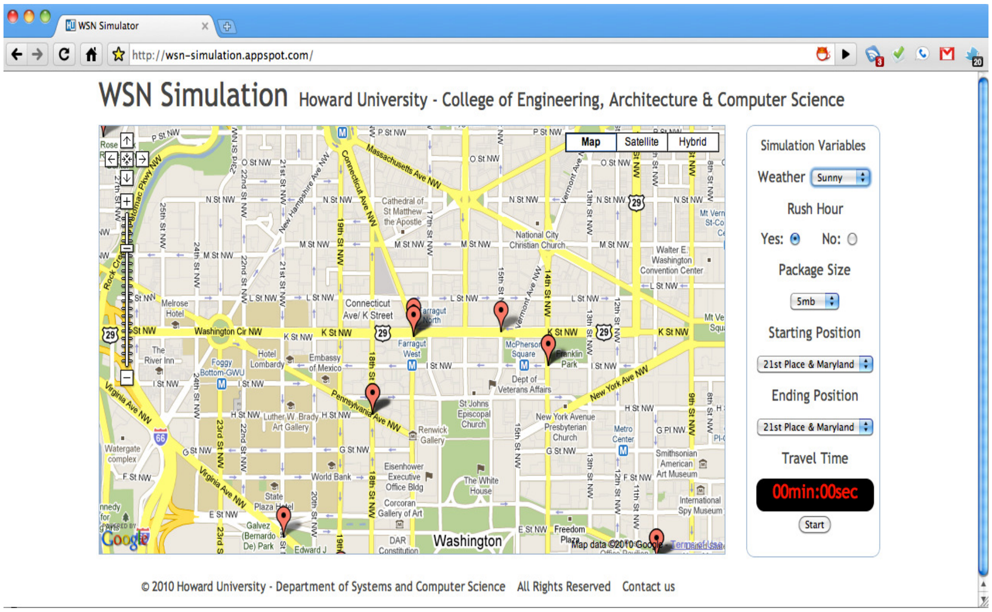

FIGURE 1: Web-Based Front End

Figure 2 presents the average end-to-end delivery delay of packets as a function of the size of the buffer. We note that, as expected, the delay is reduced when the buffer is introduced. In our previous preliminary work, we noted that a network with no store-and-forward capabilities (i.e. buffer size of 0) was significantly higher [19]. For this reason, we only focus on buffer capabilities in this work.

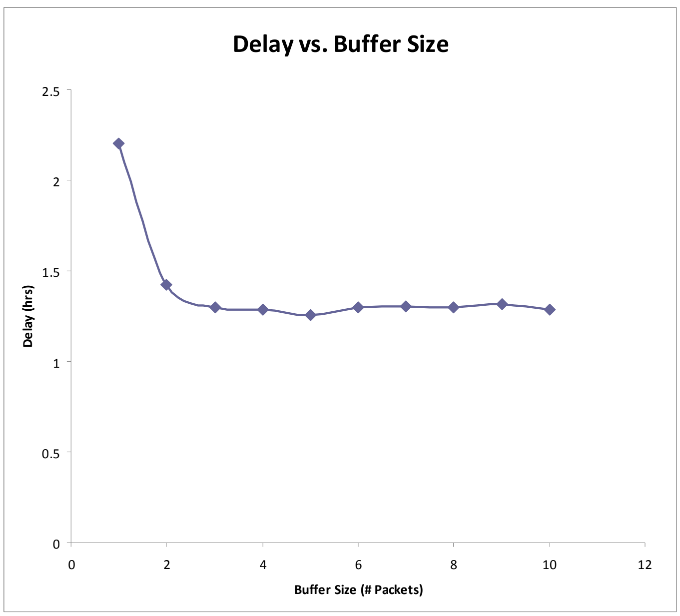

FIGURE 2: Packet Delay as a Function of Buffer Size

We also note that the delay varies slightly between 2 to 10 packets buffer size. We attribute this to a smaller number of network packets in the network. With increased number of unique packets and copies in the network, the delay variation is expected to be greater.

Figure 3 presents the average end-to-end delay as a function of the number of unique packets in the network. We note an interesting trend in this figure. As expected, as the number of packet copies increases, the end-to-end delay increases. We note the dramatic reduction in delay from 1 to 2 packets. This is due to the fact that multiple copies of an individual packet are now in the network, which allows for the probability of quicker delivery.

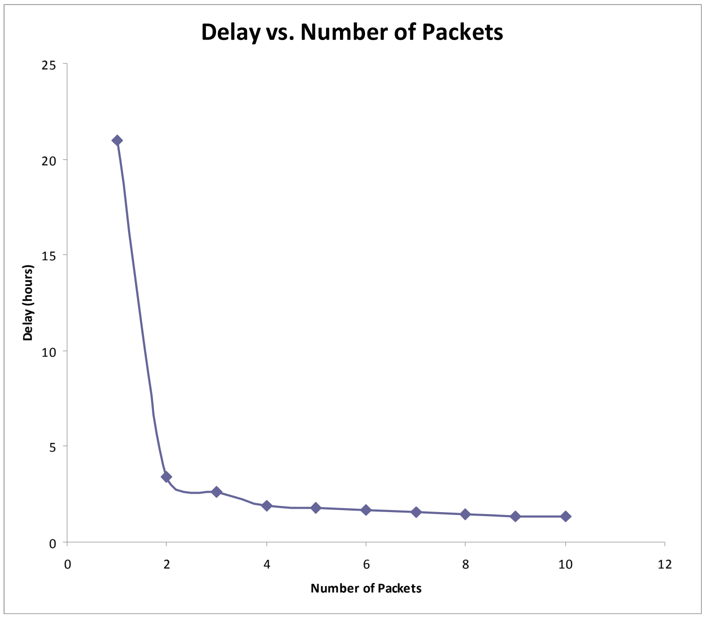

FIGURE 3: Packet Delay as a Function of Number Packets

6. CONCLUSION

In this work, we developed a discrete-event simulation to represent an opportunistic network comprised of vehicular nodes. A web-based front end was also developed via the Google Maps API, to allow a user-friendly method of manipulating network and simulation parameters. The simulation used real bus information from the Washington Metropolitan Area Transit Authority (WMATA). However, this simulation can easily analyze any system utilizing the General Transit Feed Specification (GTFS).

Currently, we are extending the capabilities of the simulation to include more unique source-destination pairs, complete parameter specification on the web-based front end, the incorporation of mobile base stations across the city, and the inclusion of additional node traffic (i.e. subway, people, cars, etc.).

We are also working on developing a model for approximating the analysis of the network. This work can ultimately be used to assist metro authorities in various cities with addressing optimization problems, such as costs, routing issues, and resource allocation. It can also be used to model the performance of various types of algorithms and protocols on such networks, including those used for emergency response, disaster relief, environmental monitoring, and more.

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Queue Size Trade Off with Modulation in 802.15.4 for Wireless Sensor Networks

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Abstract

In this paper we analyze the performance of 802.15.4 Wireless Sensor Network (WSN) and derive the queue size trade off for different modulation schemes like: Minimum Shift Keying (MSK), Quadrature Amplitude Modulation of 64 bits (QAM_64) and Binary Phase Shift Keying (BPSK) at the radio transmitter of different types of devices in IEEE 802.15.4 for WSN. It is concluded that if queue size at the PAN coordinator of 802.15.4 wireless sensor network is to be taken into consideration then QAM_64 is recommended. Also it has been concluded that if the queue size at the GTS or Non GTS end device is to be considered then BPSK should be preferred. Our results can be used for planning and deploying IEEE 802.15.4 based wireless sensor networks with specific performance demands. Overall it has been revealed that there is trade off for using various modulation schemes in WSN devices.

Keywords: WSN, Queue Size, BPSK, MSK, QAM_64.

1. INTRODUCTION

The IEEE 802.15.4 protocol is an industrial standard for Low-Rate Wireless Personal Area Network (LR-WPAN) architectures. As the primary application domain wireless sensor network applications in industrial environments can be identified. LR-WPAN is intended to become an enabling technology for WSNs. In contrast to Wireless Local Area Networks (WLAN), which is standardized by IEEE 802.11 family, LR-WPAN stresses short-range operation, low-data-rate, energy-efficiency and low-cost. An example is Zigbee, which is an open specification built on the LR-WPAN standard and focuses on the establishment and maintenance of LR-WPANs for wireless sensor networks.

The choice of the digital modulation scheme significantly affects the characteristics, performance and resulting physical realization of wireless sensor communication system derived from 802.15.4. There is no universal 'best' choice of the modulation scheme, but depending on the physical characteristics of the channel, parametric optimizations and required level of performance some will prove better fit than the others. The 802.15.4 is an IEEE standard, targeting a set of applications that require simple wireless connectivity, high throughput, very low power consumption and lower module cost. Its objective is to provide low complexity, cost and power for wireless sensor connectivity among inexpensive, fixed, portable and moving devices.

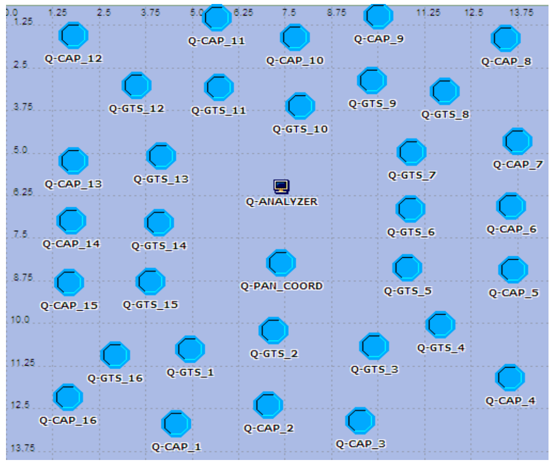
A lot of work on 802.15.4 has been reported by the various researchers [1-22]. The performance issues like: Delay; Throughput evaluation of GTS mechanism have been reported in [1]. Researchers have also studied adaptive algorithm for mapping channel quality information to modulation and coding schemes [3]. Researchers have also tried to study performance tradeoff with adaptive frame length and modulation in wireless network [4]. Some researchers have studied suboptimum receivers for DS-CDMA with BPSK modulation [5]. Researchers have also investigated voice and data transmission technique using adaptive modulation [6]. Many researchers have studied how to use queues to improve the performance of TCP [10]. Some have studied queues o dynamically allocate the channels for real-time and non-real-time traffic in cellular networks [12]. Few have studied queues for energy and QoS tradeoff for contention-based wireless sensor networks [15]. Some have worked on how to stabilize queues in large-scale networks [16]. Few researchers have studied the queues for controlling the power in wireless communication networks [20]. But none of the researchers have reported the performance comparison using different modulation schemes for 802.15.4 based on queue size. This paper proposes the comparison of different modulation schemes (QAM_64, MSK, BPSK) based on queue size to determine the suitability of 802.15.4 network.

Section [1] gives the brief introduction. Section [2] constitutes the system description which contains node model, process model, and parametric tables of the model. Section [3] shows the results and discussions derived from the experiments carried out on 802.15.4 for different modulation schemes. Finally Section [4] concludes the paper.

2. SYSTEM DESCRIPTION

The simulation model implements physical and medium access layers defined in IEEE 802.15.4 standard. The OPNET® Modeler 14.5 is used for developing 802.15.4 wireless sensor network.

(a) (b)

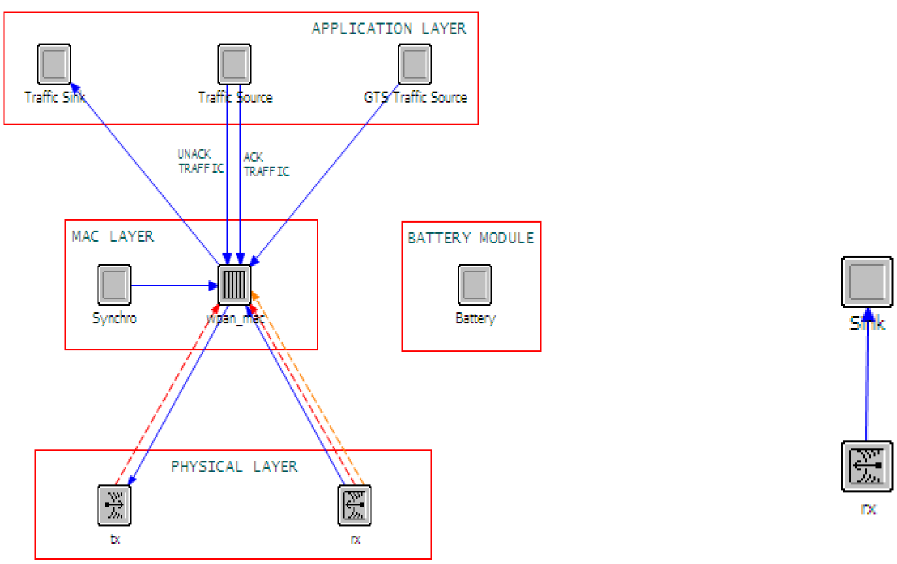


(c)

Figure 1: Network Scenarios (a) BPSK (b) MSK (c) Quadrature (QAM_64)

Figure 1 shows three different Scenarios: BPSK, MSK and QAM_64. BPSK Scenario as shown in Figure 1(a) contains one PAN Coordinator, one analyzer and thirty two end devices out of which sixteen are Guaranteed Time Slots (GTS) enabled and rest are non GTS devices. PAN Coordinator is a fully functional device which manages whole functioning of the network. Analyzer is a routing device which routes the data between PAN coordinator and the End Devices. End Devices are the fixed stations that communicate with the PAN Coordinator in Peer to Peer mode, support GTS and non GTS traffic respectively. Similar Scenarios have been created for MSK and QAM_64 as shown in figure 1 (b & c).

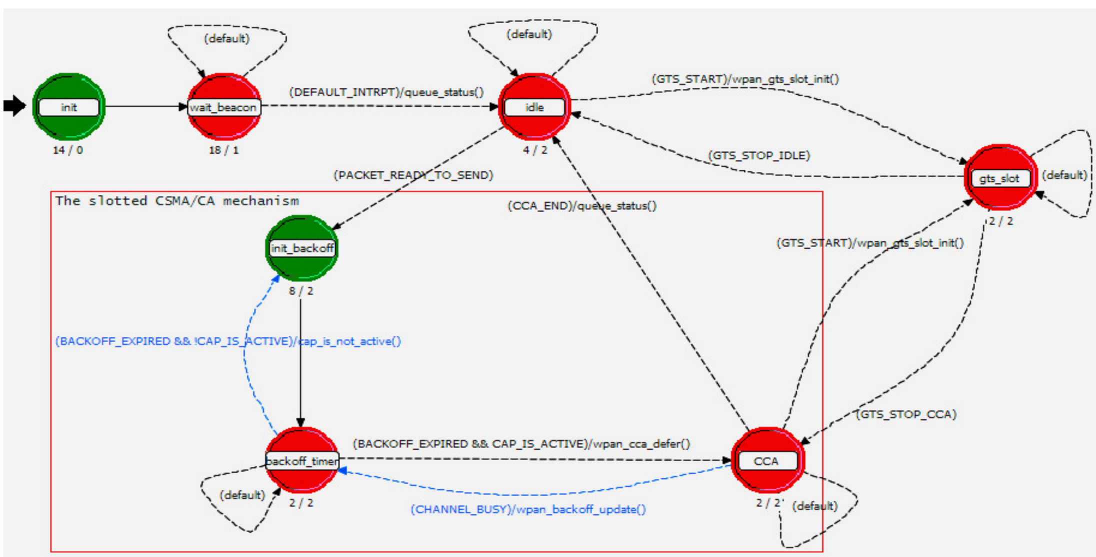
Figure 2 shows the node models for three types of WPAN devices used for modeling 802.15.4 scenarios. PAN Coordinator, GTS and Non GTS end device have the same node model as shown in Figure 2 (a) while the node model for analyzer is depicted in Figure 2 (b).



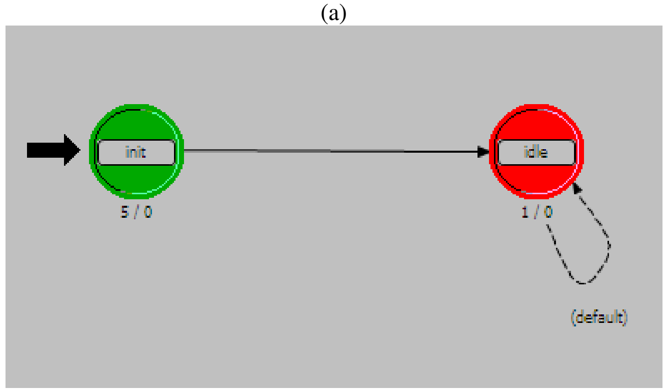
(a) (b)

Figure 2: Node Model (a) PAN Coordinator, GTS and Non GTS end device (b) Analyzer

As it has been observed from the Figure 2 (a), a node model for PAN Coordinator, GTS end device and Non GTS end device has three layers: physical, MAC and application layers. Physical layer consists of a transmitter and a receiver compliant to the IEEE 802.15.4 specification, operating at 2.4 GHz frequency band and data rate equal to 250 kbps. MAC layer implements slotted CSMA/CA and GTS mechanisms. The GTS data traffic coming 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 slotted CSMA/CA algorithm are transmitted to the network during the active Contention Access Period (CAP). This layer is also responsible for the generation of beacon frames and synchronizing the network when a given node acts as a PAN Coordinator. Finally is the topmost application layer which is responsible for generation and reception of traffic consists of two data traffic generators (i.e. Traffic Source and GTS Traffic Source) and one traffic sink. The traffic source generates acknowledged and unacknowledged data frames transmitted during CAP. GTS traffic source can produce acknowledged and unacknowledged time-critical data frames using GTS mechanism. The traffic sink module receives frames forwarded from lower layers. Figure 2 (b) shows the node model for the analyzer which consists of sink and a radio receiver.
Corresponding process models for PAN Coordinator, GTS end device, Non GTS end device and analyzer that deals with each and every operation on the data are depicted in Figure 3:



(a)



(b)

Figure 3: Process model (a) PAN Coordinator, GTS and Non GTS end device (b) Analyzer

Figure 3 (a) shows the process model for the PAN Coordinator, GTS and Non GTS end device. It consists of the various states: Init whose function is to initialize MAC and GTS scheduling;

Wait_beacon which is responsible for synchronizing the traffic of the node with rest of the WPAN in order to minimize the collisions; Idle which is responsible for introducing delays in order to make the maximum use of the resources; gts_slot which is responsible for generation, reception and management of GTS traffic; Backoff_timer used for sensing the medium and transfer of data, CCA - for interrupt processing. Similarly figure 3 (b) shows the process model for analyzer which consists of init and idle states. Basically the process model explains how the data is sent from the generating node to the PAN Coordinator, taking into consideration the availability of PAN Coordinator as it has to communicate with the other similar nodes.

Here three different Scenarios have been created with three different modulation formats like: BPSK, MSK and QAM_64. Following parameters have been set for these scenarios as shown in the table 1 like: in GTS settings the value of GTS permit is common for all three types of devices i.e. enabled.

Parameter \ Scenario	PAN Coordinator	GTS Enabled End Device	Non GTS End Device
Modulation	BPSK, MSK, QAM_64		
Acknowledged Traffic Source			
Destination MAC Address	Broadcast	PAN Coordinator	
MSDU Interarrival Time (sec)	Exponential(1.0)	Constant (1.0)	Exponential(1.0)
MSDU Size (bits)	Exponential(912)	Constant (0.0)	Exponential(912)
Start Time (sec)	0.0	Infinity	1.0
Stop Time (sec)	Infinity		
Unacknowledged Traffic Source			
MSDU Interarrival Time (sec)	Exponential(1.0)	Constant (1.0)	Exponential(1.0)
MSDU Size (bits)	Exponential(912)	Constant (0.0)	Exponential(912)
Start Time (sec)	0.1	Infinity	1.1
Stop Time (sec)	Infinity		
CSMA/CA Parameters			
Maximum Back-off Number	4		
Minimum Back-off Exponent	3		
IEEE 802.15.4			
Device Mode	PAN coordinator	End Device	
MAC Address	Auto Assigned		
WPAN Settings			
Beacon Order	14	7	
Superframe Order	6		
PAN ID	0		
Logging			
Enable Logging	Enabled		
GTS Settings			
GTS Permit	Enabled		
Start Time	0.0	0.1	Infinity
Stop Time	Infinity		
Length (slots)	1		0
Direction	Receive	Transmit	
Buffer Capacity (bits)	10,000	1000	
GTS Traffic Parameters			
MSDU Interarrival Time (sec)	Exponential(1.0)		Constant (1.0)
MSDU Size (bits)	Exponential(912)		Constant (0.0)
Acknowledgement	Enabled		Disabled

Table 1: Parametric values for PAN Coordinator, GTS and Non GTS End Device in BPSK, MSK and QAM_64 Scenarios

3. RESULTS AND DISCUSSIONS

Simulation has been carried out for the three different scenarios of IEEE 802.15.4 using QAM_64, MSK and BPSK. In this section results for the queue size at the radio transmitter have been presented and discussed for different types of devices in wireless sensor networks like: Fully Functional Device (FFD) – those devices that control the network and manage the routing tables and communicate with each of the device in peer to peer mode, Reduced Functional Devices (RFD) – those devices which can only communicate to the FFD but not to each other.

Radio Transmitter Queue Size

3.1.1 FFD – PAN Coordinator

Figure 4 below indicates the queue size at the radio transmitter of a PAN Coordinator. It is observed that it is 0.2926, 0.2572 and 0.2261 packets for MSK, BPSK and QAM_64 respectively. It has been experimentally proved that queue size is maximum in case of MSK because it purposefully generates the delays to reduce the phase shifts to produce amplifier-friendly signals which results in the long queues at the radio transmitter as compared to the other modulation schemes (e.g. BPSK, QAM_64 etc.) and also MSK has self synchronizing capability [17]. While it has been observed that queue size is minimum in case of QAM_64 as it increases the efficiency of transmission by utilizing both amplitude and phase variations [17, 23].

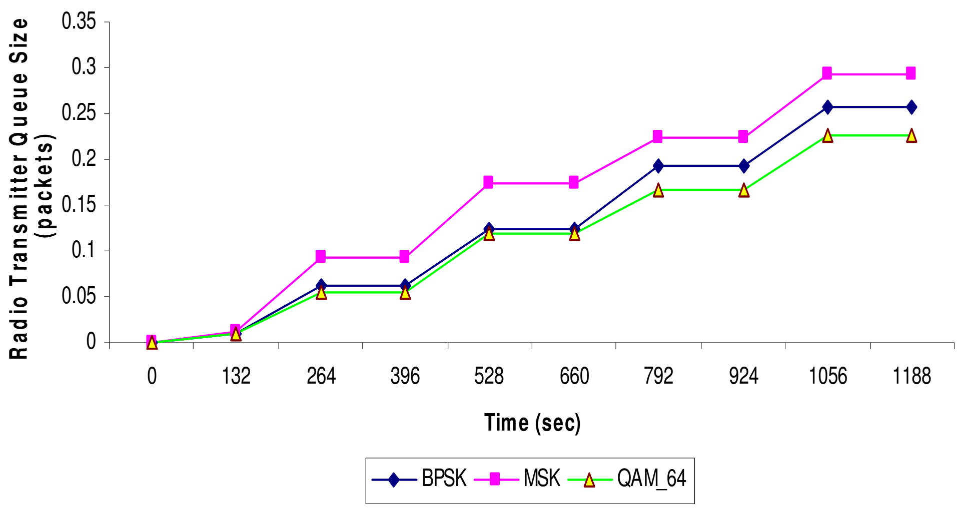


Figure 4: Radio Transmitter Queue Size at PAN Coordinator

3.1.2 RFD – GTS End Device

Figure 5 indicates the queue size at the radio transmitter of a GTS end device. It is 0.0179, 0.0020 and 0.0013 packets MSK, QAM_64 and BPSK respectively. It has been observed that queue size is maximum in case of MSK [17]. While it is minimum in case of BPSK as it can modulate only 01 bit/sec and there is strong synchronization between the transmitter and the receiver [23].

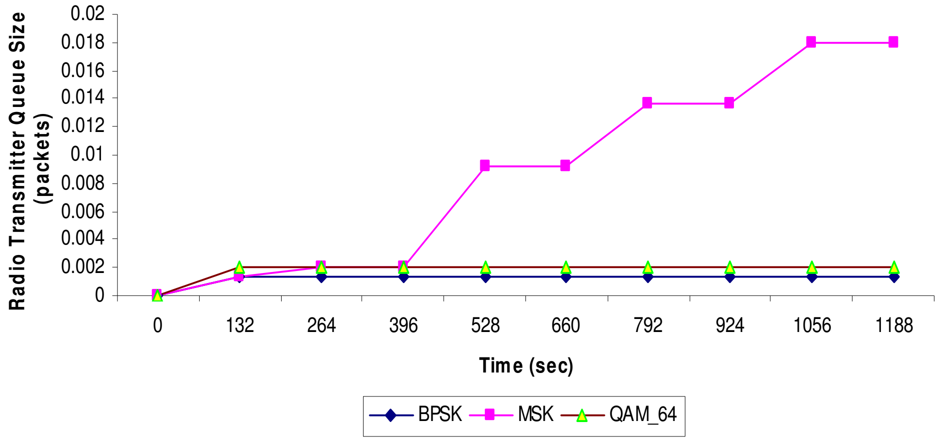


Figure 5: Radio Transmitter Queue Size at GTS End Device

3.1.3 RFD – Non GTS End Device

Figure 6 reveals the queue size at the radio transmitter of a Non GTS end device. It is 0.1621, 0.1340 and 0.1172 packets for MSK, QAM_64 and BPSK respectively. It has been observed that it is maximum in case of MSK [17], while it is minimum in case of BPSK [23].

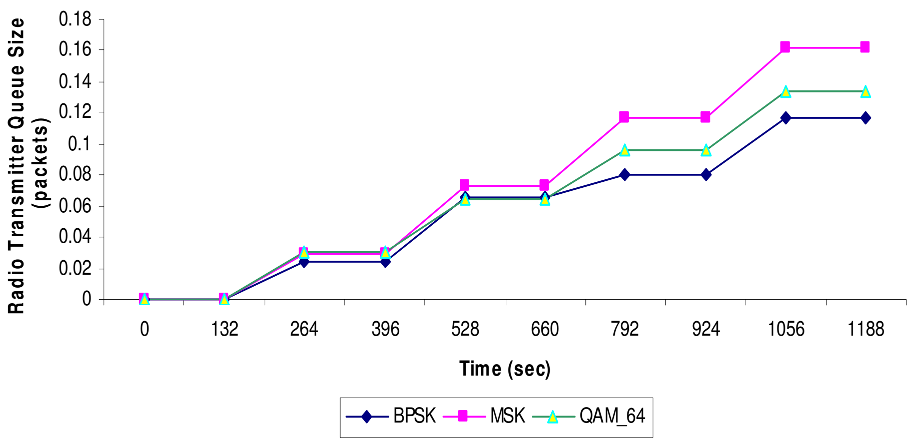


Figure 6: Radio Transmitter Queue Size at Non GTS End Device

From the results obtained in figures: 4 for FFD and 5 & 6 for RFD (GTS & Non GTS), it has been concluded that if queue size at the PAN coordinator of 802.15.4 wireless sensor network is to be taken into consideration then QAM_64 should be preferred and if queue size at the GTS or Non GTS end device is to be considered then BPSK should be preferred.

4. CONSLUSION

This paper presents the queue size at the radio transmitter of 802.15.4 wireless sensor network using OPNET® Modeler 14.5. Here three different modulation scenarios for BPSK, MSK and QAM_64 have been considered. Results reveals that queue size at the radio transmitter of PAN Coordinator, GTS and Non GTS End Device is [0.2926, 0.2261, 0.2572], [0.0179, 0.0020, 0.0013] and [0.1621, 0.1340, 0.1172] packets for MSK, QAM_64 and BPSK respectively. It is concluded that QAM_64 at the fully functional device and BPSK at the GTS and Non GTS RFDs should be implemented if queue size at the radio transmitter of 802.15.4 WSN is to be minimized. Also it is concluded that MSK at all type of devices in 802.15.4 for WSN is unsuitable as it results in the larger queues as compared to the other modulation formats at all type of devices, as larger the queues, larger will be the delays.

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