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.

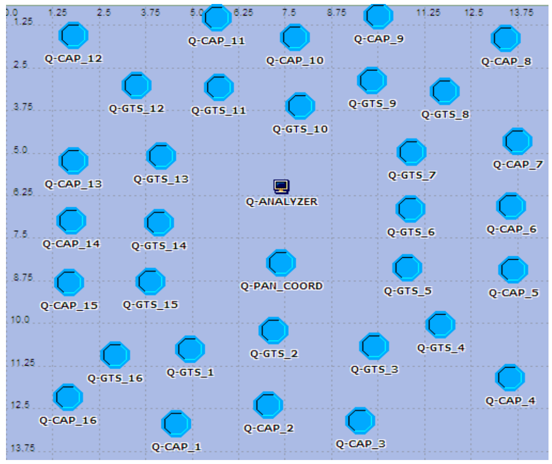
A lot of work on 802.15.4 has been reported by the various researchers [1-22]. The performance issues like: Delay; Throughput evaluation of GTS mechanism have been reported in [1]. Researchers have also studied adaptive algorithm for mapping channel quality information to modulation and coding schemes [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)

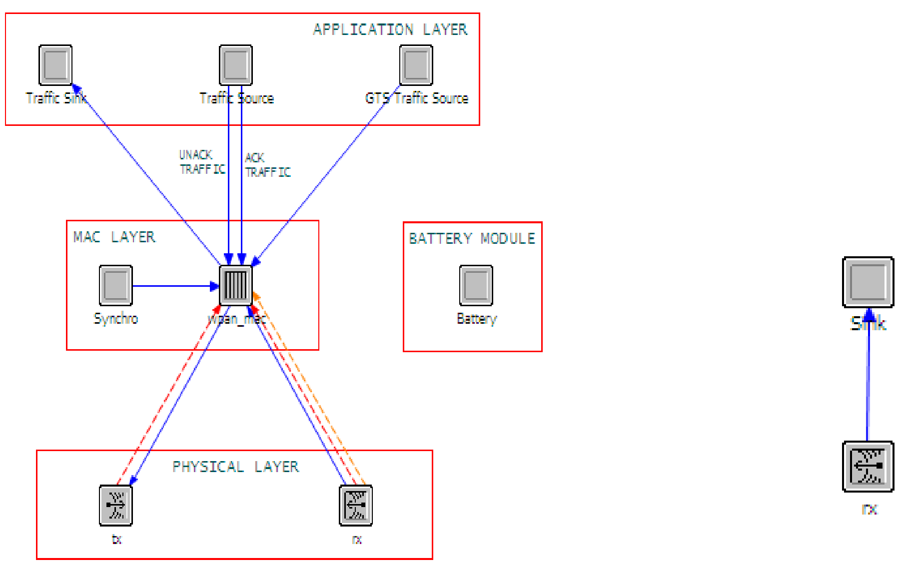


(c)

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).

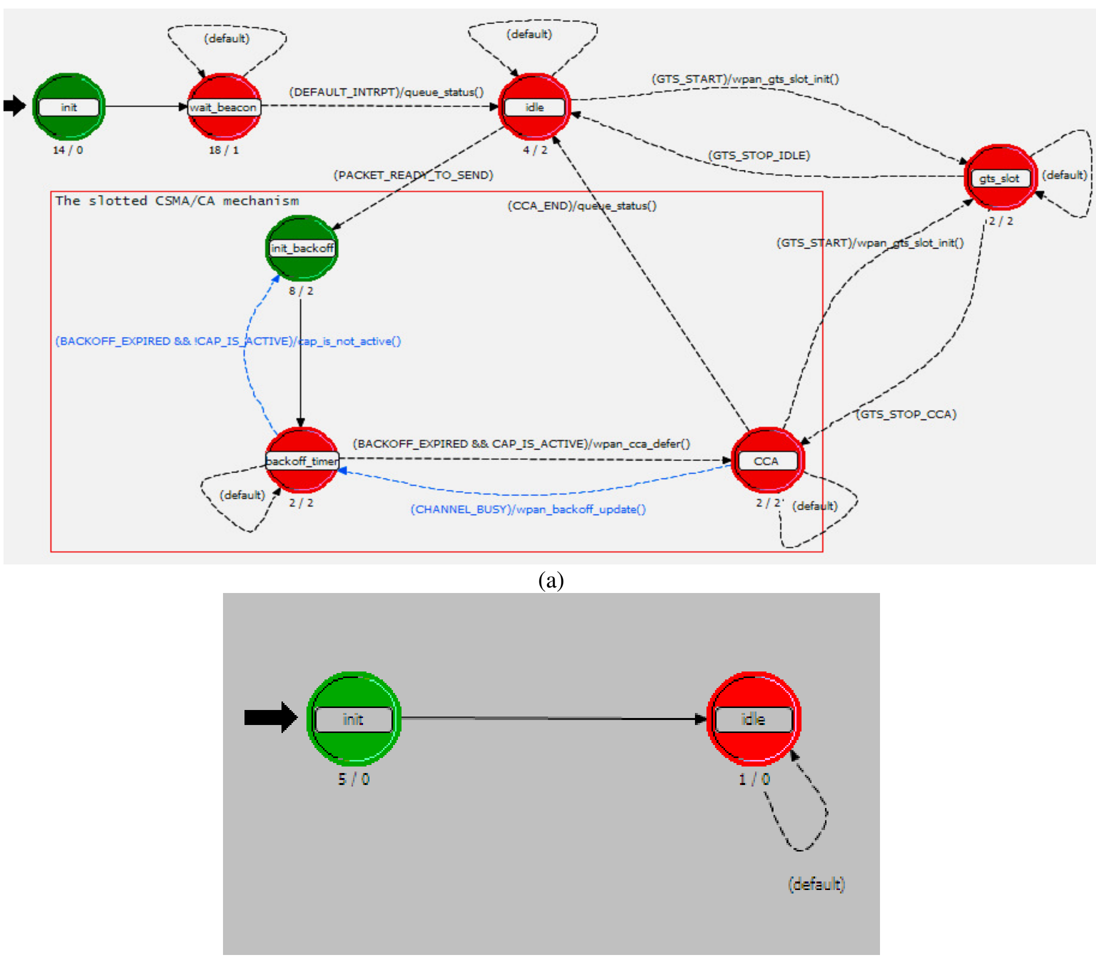
Figure 2 shows the node models for three types of WPAN devices used for modeling 802.15.4 scenarios. PAN Coordinator, GTS and Non GTS end device have the same node model as shown in Figure 2 (a) while the node model for analyzer is depicted in Figure 2 (b).



(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].

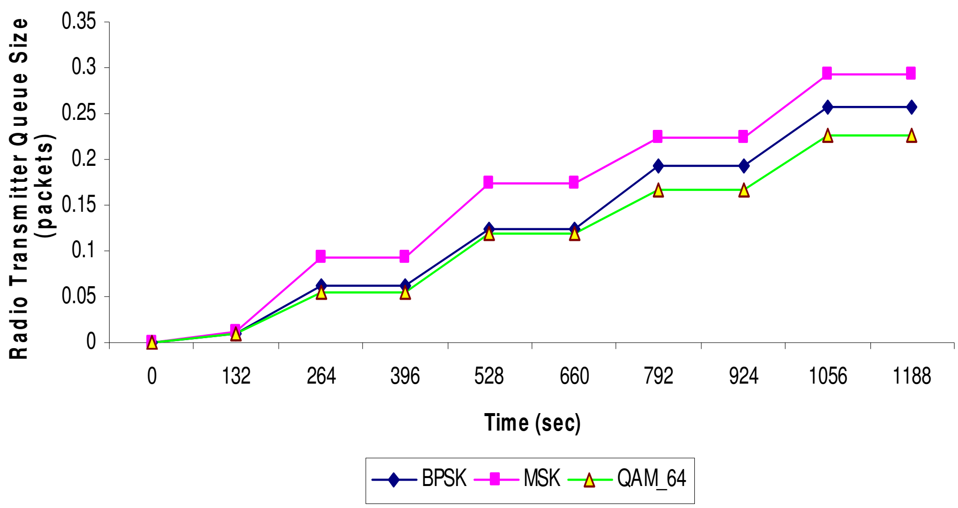


Figure 4: Radio Transmitter Queue Size at PAN Coordinator

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].

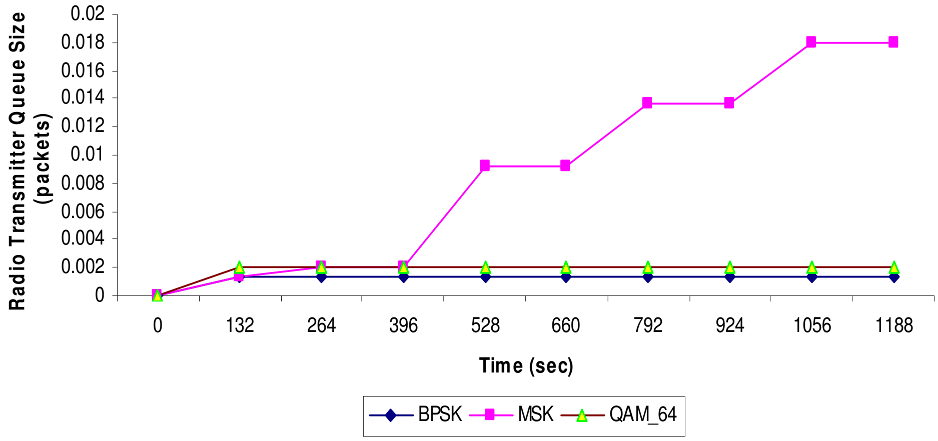


Figure 5: Radio Transmitter Queue Size at GTS End Device

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].

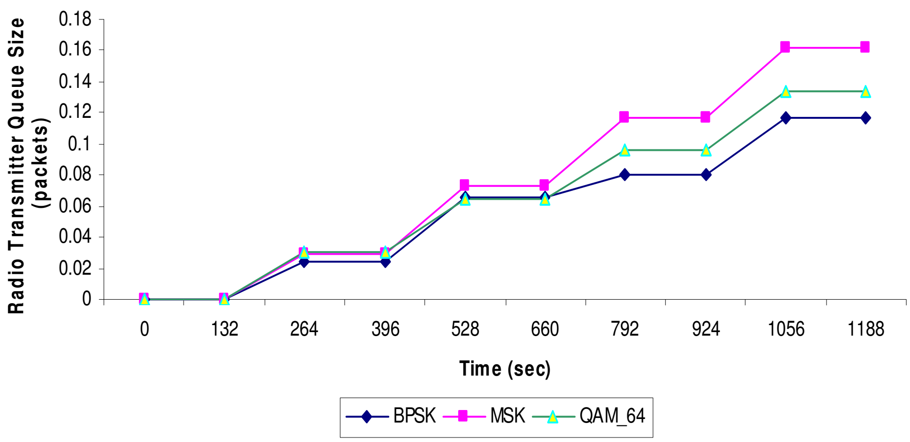


Figure 6: Radio Transmitter Queue Size at Non GTS End Device

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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