

# Impact of Duty Cycle Variation on WSNs<sup>1</sup>

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**Abstract**— Wireless Sensor Networks (WSNs) operate with varying duty cycles to meet their application-specific criteria such as the availability, reliability, and the life expectancy of the system. This variation in duty cycle consequently affects the system characteristics including the interference and collision of signals. However, the sensitivity to physical jamming attacks with respect to duty cycle of the network is not widely explored area of research. This paper presents a detailed analysis of the effect of the duty cycle to the interference and collision of signals in the WSNs. In particular, our simulation model depicts a log normal shadowing model to represent a realistic wireless channel and observe the effects of duty cycle variation when a physical jamming attack is launched on the network using a compromised node. Our results show that setting the duty cycle at pre-determined value would help minimize the packet drop ratio of the network.

**Keywords**—Duty Cycle; Packet Drop Ratio; Wireless Communication, Deployment

## I. INTRODUCTION

Wireless Sensor Networks (WSNs) are expected to be a key technology that would affect our life in this century [1]. Such networks have substantial data acquisition and data processing capabilities and for this reason, are deployed densely throughout the area where they will monitor specific phenomena. Much research has been done with the aim of connecting large numbers of these sensors to create robust and scalable WSNs on the order of hundreds of thousands of devices [2]. As this technology is maturing, proposed applications have increased from battlefield surveillance to health care and industrial as well as habitat monitoring [3]. With the availability of sensors for these networks for the phenomenon under observation, the application domains would continue to explode further. Large scale deployment of WSNs need to be carefully thought of, as making any changes post-deployment would be either technically infeasible or prohibitively costly in most of the cases. This understanding has led to the spurt of research activities currently under progress, most of which are modeling and/or simulation based with some prototype/test bed implementations.

IEEE 802.15.4 [32] is the standard using ISM band for wireless personal area networks, which is now being popularly used for WSNs with a number of manufacturers supporting it [23]. In [31] a performance evaluation of IEEE 802.15.4 has been made and the authors conclude that this standard is suitable for simple and non-complex applications. While their analysis addresses many issues, the impact of duty cycle has not been studied. This paper presents the impact of duty cycle on a WSN for periodic data gathering with uniformly distributed deployment using IEEE 802.15.4. The simulations have been done using Castalia framework on OMNeT++ [25, 26]. The motivation for the work is explained in section 2. Section 3 highlights the experimental setup, followed by section 4 providing analysis of the results. Section 5 concludes the paper with future work.

## II. MOTIVATION

WSN uses a layered protocol stack, like typical computer communication networks [4]. This approach has its chief advantages in terms of manageability and addressed the needs for separation of concerns. However, communication across different layers seems to provide certain advantages for optimizing performances of protocols at other layers, and cases of cross-layer protocol communication particularly relevant for WSN are at [5] [6]. A major limitation of WSN nodes is the availability of limited resources. This resource-constrained nature of WSN nodes has posed several challenges and the scientific community at large has been addressing them in multiple ways. Low foot-print operating systems (eg., TinyOS [7]) and programming languages (eg., nesC [8]) are available for developing applications.

The revolution in semiconductor industry has made getting acceptable form-factor for sensor nodes a reality. One critical area where size reduction has been a challenge is the energy source, and the idea of rechargeable energy sources is faced with myriad of challenges with no feasible solution in sight in near future [9]. All these have led to researchers focusing on energy conservation and minimization to have the WSN lifetime extended. A significant research work has been devoted to energy conservation by devising techniques at each of layer of the protocols as reported by [10][11]. Majority of the work is targeted to reduce the number of transmissions as it consumes much more energy than computation. Another

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approach used is to control the transmission range and to increase number of hops to the destination. In this approach, while reduced radio range reduces the collision chances, it increases the total number of transmissions due to the additional hops. In a way, they offset each other and there may not be significant improvements, unless specific implementation architecture ensures effective reduction in number of transmissions. Transmission power control algorithms have been studied by many with encouraging results, which are not realistic in most cases, as shown by [13]. In fact, in [12] the authors claim that the number one myth about energy consumption in wireless communication is that multi-hopping saves energy and suggest that great care should be taken when applying multi-hopping with the aim of improved energy efficiency. There is yet another aspect to the operations of the WSN that is more topology dependent rather than protocol dependent, which is the duty cycle of sensor nodes. To our understanding most of the research associates duty cycle with low power [14] [15] and dynamic sleep/wakeup is controlled by the algorithm [29]. Duty cycle affects the collision and interference properties of the channel. In this paper the impact of duty cycle on a uniformly distributed, data reporting WSN model is studied.

The sensor nodes communicate using wireless medium. Energy consumption for communication depends on the properties of the wireless medium. For modeling of the wireless medium, in general, or the specific channel being used in particular, some algorithm designers use simplistic models and hence the projected performance and the actual performance tend to substantially mismatch. For example, in [22] the authors assume a simple unit-disc wireless channel model. A number of studies have shown that the wireless channel models are far from being unit-disc, and they differ widely depending on the frequency range, and some of them specifically for IEEE 802.11 [17-20][30]. In fact, wireless channels have unique properties that depend on many parameters that include frequency of operation, atmospheric conditions, terrain/objects in the channel, transmitter power, receiver sensitivity, modulation schemes, and so on [16]. A more realistic log normal shadowing model for 802.15.4 is proposed by [21], which is supported by many of the WSN platforms currently available [23]. Disregarding the distance-independent terms in these energy costs and only assuming a simplified energy cost proportional to some power of the distance has been called “one of the top five myths” of energy consumption in radio communication [12].

All these above point to the need of using realistic models if theoretical and simulation studies were to better depict the behavior of real WSNs. The importance of using realistic environment, while proposing a framework for performance evaluation, is also emphasized in [24].

### III. SIMULATION SETUP

Of the many network simulators that are available, we use OMNeT++ [25], which is a discrete event simulator. A WSN framework offered on top of OMNeT++ is Castalia [26]

available from National ICT, Australia. In [27] the importance of accurate simulation and the benefits of using Castalia framework is explained. By using this, our simulation uses a realistic WSN node, using CC2420 MICA2 motes by [28]. It may be noted that any other wireless mote could have been in its place as long as the detailed data sheet of the mote is available. The wireless channel model used is the log-normal shadowing model.

As shown in Figure 1, a sample scenario of uniformly distributed grid type deployment with random noise in grid positions is used. It may be noted that the noise to the grid position is to ensure the simulation to be as close to real implementation as possible. Applications requiring this type of deployment are many monitoring ones including industrial, environmental, and health where periodically specific phenomena need to be reported for alarm and event reporting for follow up actions.

The details of basic simulation set up are given in Table 1. The protocol stack includes application, routing, media access control and physical layers. Standard CSMA/CA model is used to reduce collisions. Due to the properties of the mote, once transmission starts the radio cannot listen.

TABLE 1: Pertinent details of simulation setup

Number of nodes	9	9	16
Network Dimension	80m x 80m	60m x 60m	120m x 120m
Duration of Simulation	Varying 100 to 6000 seconds		
Duty Cycle	Varies from 0 to 1		
Frequency band	2.4GHz		
Distribution	Grid Deployment with random noise		
Number of trials	Varying		
Mote model	MICA2 CC2420		

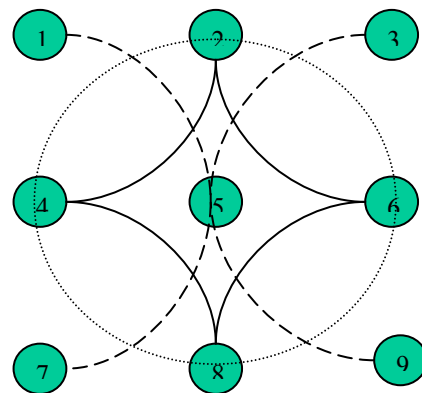


Figure 1. Edge, Center, and Corner node coverage

Figure 1 shows the neighbors for each node. As can be seen the center node has neighbors all around, where as the edge nodes other than corner ones (nodes at numbered 2, 4, 6 and 8) have neighbors in 2 quadrants as shown by dashed

lines. The corner nodes (numbered 1, 3, 7 and 9) have neighbors in just a single quadrant. The application simply senses a physical parameter like ambient light periodically and reports it to the sink. If clustered deployment is considered, then without loss of generality, this model can be considered as representing cluster heads in place of nodes.

The simulations were carried out for different network sizes and different durations, and some of them were run multiple times with the duration varying from as low as 100 seconds to 6000 seconds. Our results showed that simulation in excess of 300 seconds were stable and providing consistent results. So we decided to run the simulations for 600 seconds. For the purpose of discussions, we report the results when a 9-node sensor network was deployed with area of deployment of 80 x 80 and 60 x 60 square meters. Spacing beyond 80 x 80 square meters resulted in a sparse network with lack of sufficient radio range while spacing them closer than 60 x 60 square meters resulted in significant amount of collisions. Similarly, when the duty cycle drops below 0.2 the number of packets that could be received by any node is negligible and hence they are not shown.

In wireless networks, every radio receiver could find out the packets lost due to collision as well as interference, whenever they are awake. These two factors are essentially accounted for additional transmissions and permanent loss of data packets while consuming precious energy. The other alternative is to have centralized control of transmissions that will make the WSN concept unviable for most of the applications. In short, they are the essential evils, which wireless communication networks need to live with. Collisions happen due to simultaneous presence of more than one transmission. By interference we refer to the situation where the packets are received by the radio but are found corrupted or unusable by higher layers of the protocol stack. Typically while collision could be avoided by use of suitable protocols, interference is handled by error correction mechanisms. Our interest here is to find out the impact of duty cycle for both the cases as they negatively affect the performance of the WSN.

For the purpose of this evaluation we define the following terms:

$$PDR_c = \text{packets lost due to collisions} / \text{total number of packets expected to be received} \quad (1)$$

where  $PDR_c$  is the Packet Drop Ratio (PDR) due to collisions.

$$PDR_i = \text{packets lost due to interference} / \text{total number of packets received by radio} \quad (2)$$

where  $PDR_i$  is the PDR due only to interference. Essentially this is the ratio of number of packets received before processing by higher order layers to the correctly received number of packets.

$$PDR_t = (PDR_c + PDR_i) / \text{total number of packets expected to be received} \quad (3)$$

where  $PDR_t$  is the total or effective PDR.

#### IV. EFFECTS OF COLLISION

As can be seen in Figure 2, the  $PDR_c$  decreases with duty cycle till about 0.4 after which it again increases. This can be explained by the fact that when the radio is awake most of the time, it listens to significant amount of transmissions and hence the chances of collision are high.

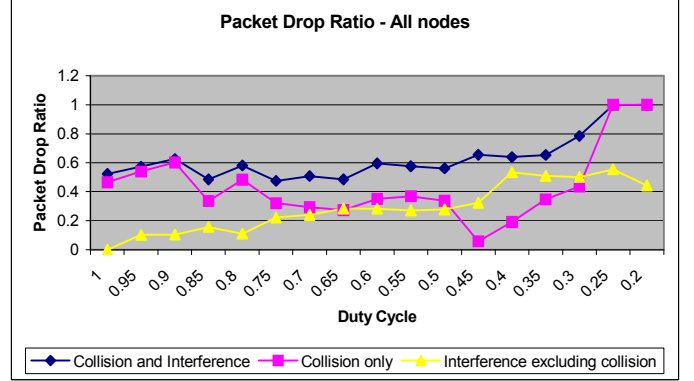


Figure 2. Packet Drop Ratio for all nodes

However, at the other end, when it is awake only for a short period, the effect of each packet being dropped increases due to less number of packets as well as the radio's need to send every time it is awake.

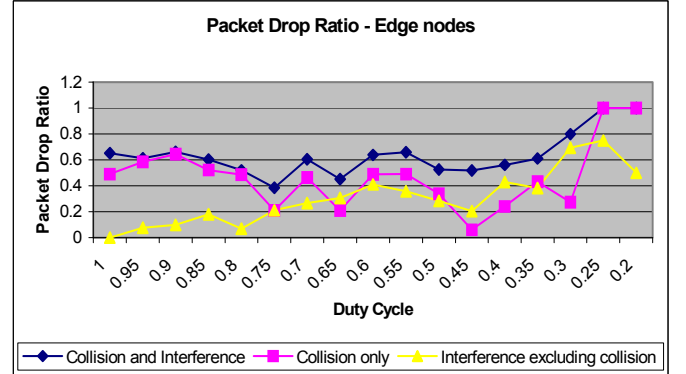


Figure 3. Packet Drop Ratio for all edge nodes (two quadrants)

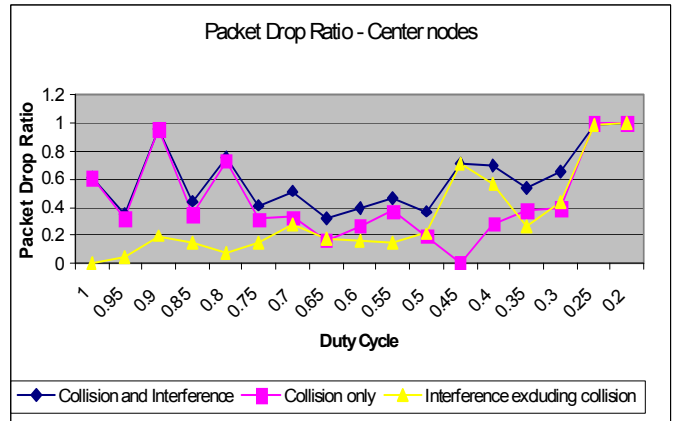


Figure 4. Packet Drop Ratio for center nodes (all four quadrants)

In cases where the radio is awake for a longer time, it may be listening sometimes with no data to transmit, which makes this dip, where  $PDR_c$  reaches a minimum at about 50% duty cycle. This remains true for all cases of the node locations, as can be seen from figures 3 to 5. All of them point to about 45 to 65% as the optimal duty cycle to minimize collisions. Figure 5 shows the summary of findings when the sensors are deployed closer the optimal duty cycle to minimize collisions with reasonable number of packets seems to be between 50 to 60%.

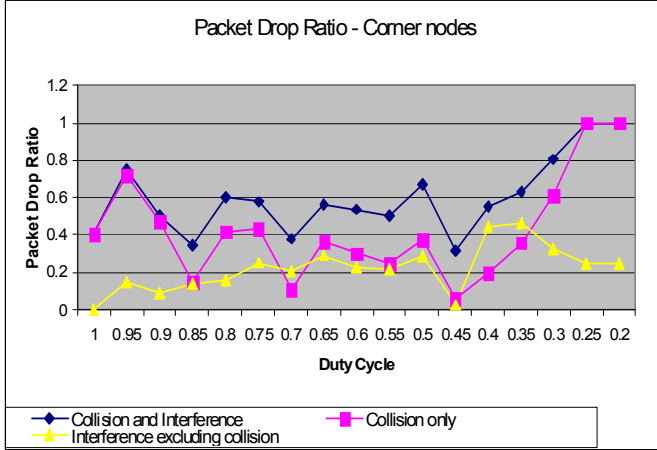


Figure 5. Packet Drop Ratio for all corner nodes (single quadrant)

## V. EFFECTS OF INTERFERENCE

Interference due to the inherent properties of channel, which could be natural or manmade are characterized by bit-error-rate, delay, and jitter. All these result in part of the transmission data getting corrupted. Interference is typically countered by error detection and correction mechanisms. Additional bits required for these mechanisms increase both computation and communication overheads, which are expected to be offset by the reduction in number of packets that need to be retransmitted. Our analysis of the simulation results shows that interference increases with decrease in duty cycle.

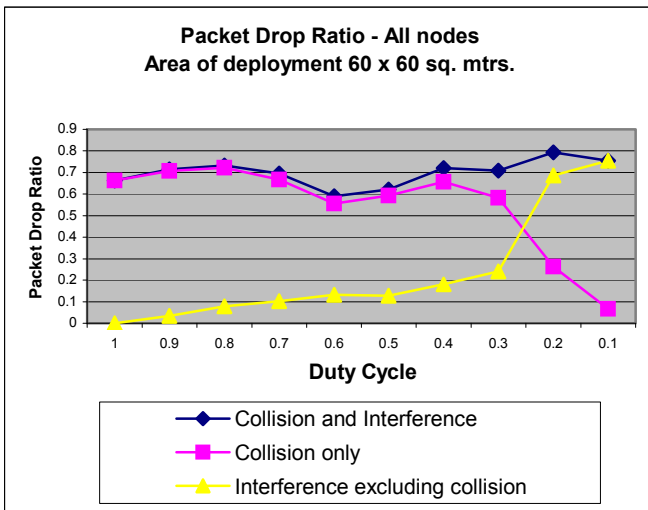


Figure 6. Packet Drop Ratio for all nodes (denser deployment with less spacing)

This looks contrary to general radio channel properties where reduced number of radios amount to reduced radio noise or increased radio silence and hence interference should decrease. This could be explained by the fact that as the duty cycle increases, the number of packets received by the higher layer protocols decreases due to the increased collision rate. Contrary to collision effects, in case of interference, the  $PDR_i$  increases as the duty cycle reduces, in general. The  $PDR_i$  overtakes  $PDR_c$  when the duty cycle is about 45% after which PDR starts shooting up. From figures 3 to 5, a duty cycle of 45% seems optimal. From figure 6 it can be seen that as the sensor spacing reduces, even though the overall PDR behavior is similar, when the duty cycle reduces below 30% the PDR shoots up

## VI. OVERALL ANALYSIS

The net effect of collision and interference is studied by analyzing the overall PDR. The overall PDR seems optimal for duty cycles that are around 60%. To ensure that these values hold good for larger deployments we have added figure 7, which shows deployment of 16 sensors over a 120 x 120 square meters area and as can be seen, the results are surprisingly similar pointing to an optimal duty cycle of 60%.

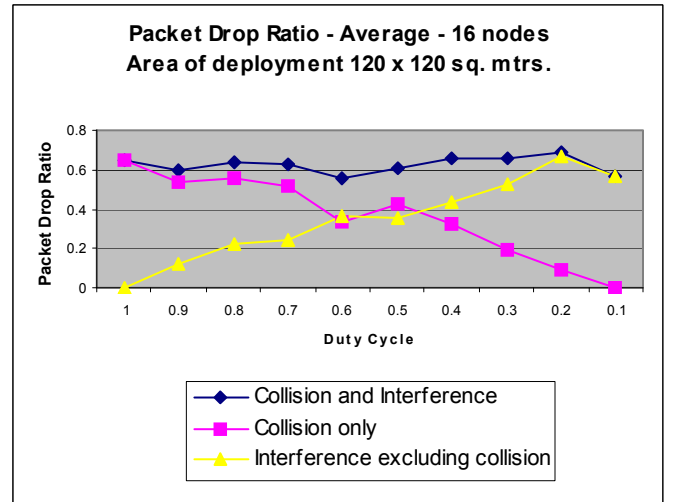


Figure 7. Packet Drop Ratio for all nodes (16 node deployment)

## VII. CONCLUSION

By simulating different configurations with multiple spacing's and nodes, the authors studied the impact of duty cycle for WSNs. We conclude that if a duty cycle of about 60% is used, then optimal performance is achieved with minimum PDR and position of the node does not affect the performance as much as one would expect. Also, when a compromised node is used for jamming, unless the duty cycle of the jammer is varied significantly, no major effect in PDR is observed, unless the node is used to transmit continuously, which is an inefficient way of jamming as the jamming node would die exhausting its energy source soon. We plan to investigate identification of such jammer by observing changes in PDR as an extension of this work.

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