On the Homogeneous Transmission Power under the SINR Model

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Abstract: Power control is quite important in the field of wireless sensor networks. Many works adjust transmission power in order to either achieve significant improvement on packet reception or to save energy. Even though the use of non-homogeneous transmission power utilisation benefits is evident in the literature, we study cases where the use of homogeneous transmission powers across parts of the network may accomplish high Packet Reception Ratio. We show examples of the above and provide experimental results that show that reception of packets may be high in appropriate topologies or parts of the topology, with the use of the same transmission power level. We evaluate two topologies with and without the use of Clear Channel assessment to present our point.

1 INTRODUCTION

Wireless sensor networks (WSN) are going to the second decade research, as shown by Breza, Martins, McCann, Spyrou, Yadav and Yang (2010). The main reason behind this trend is the plethora of civil and military applications that require the gathering of data and their successful wireless transmission within a large terrain. WSNs consist of small wireless devices that measure physical phenomena such as temperature, pressure, humidity, or the position of objects.

The distributed nature of WSNs, where devices exchange information with others within their transmission range, can be quite useful. However, this very advantage is the main drawback of WSNs. The nature of the radio employed by the devices is shared by all participants in the transmission range; hence, the issue of interference is addressed. It is intuitive that simultaneous transmission might result in drop of packets, since the communication medium suffers from interference. Such a phenomenon is evident with the use of graph-based models.

This has a direct impact on the network capacity and throughput. In order to face the problem of interference, we can address the issue of adjusting transmission powers. Successful adjustment of transmission powers result in a smaller set of interferers; hence, an increase of network throughput. It is imperative that we use the most appropriate interference model to attempt to tackle this problem. We utilize the physical SINR model by Gupta and Kumar (2000), where interference is continuous and decreasing polynomially with distance from the sending device. We will provide the reader with a formal description of the model at a later section of the paper.

Briefly outlining the model, the receivers successfully receives a message if the ratio of the signal strength of the sender and the sum of interference signals by devices, transmitting at the same time, is larger than the hardware-defined threshold. The denominator of the ratio also includes ambient noise. The speed that the signal fades depends on the variable called the path-loss exponent α, dictated by Rappaport (1996), which takes the value ranging from 2 - 6 according to environment of the transmission. The accumulative nature of interference provides a fruitful domain of research. Only recently have some theoretical guarantees been provided for SINR-based algorithms.

Power control is an important field in the field of wireless networks, since it can control the performance of the network. Furthermore, it may increase the number of receivers for a given sender, as well as tuning interference. However, power assignment has a significant impact on the complexity of the problems addressed by algorithms. In the

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literature, power assignment is distinguished between uniform and non-uniform settings. As implied by the two different approaches, uniform assignment sets the same transmission power to all nodes. On the other hand, in the non-uniform assignment, senders operate on different transmission powers offered by the communication medium.

Moscibroda, Wattenhofer, and Zollinger (2006) as well as Moscibroda, Wattenhofer, and Weber (2006), show that uniform power assignment exhibits performance disadvantages as opposed to a non-uniform one. However, cases where power control approaches outperform uniform power assignment schemes position the nodes in an area of exponential size in the number of nodes. These schemes require transmission power levels that differ by a factor exponential in the number of nodes, as shown by Avin, Lotker and Pignolet (2009). A uniform power control has a number of advantages due to it being simple.

Some of them include the lower cost of transmitting at the same transmission power. The simplicity of decision making implies lower cost, since devices do not need to decide their power level depending on factors, such as interference. In addition, Avin C., Emek Y., Kantor E., Lotker Z., Peleg D. and Roditty L., (2009), showed the convexity of reception zones of senders using a uniform scheme. This is not the case for the non-uniform scheme.

In this paper, we will build upon the results of Moscibroda, Wattenhoffer and Weber, (2006) that show that senders may transmit simultaneously and messages will be received without collision due to interference. We show that simultaneous transmission of messages is feasible even with the use of uniform transmission powers, which depends on the distance of the interfering nodes with the receivers.

2 RELATED WORK

There is a significant difference between the graph based and the SINR models. Early works investigate the SINR model based on the assumption of nodes being uniformly distributed in the plane, such as (Behzad and Rubin, 2003), (Grönkvist and Hansson, 2001). The complexity of these solutions, however, gave way to computationally efficient approaches, which provide guarantees that use SINR effects. These solutions include scheduling (Moscibroda and Wattenhofer, 2006) and topology control (Moscibroda, Wattenhofer, and Weber, 2006).

Since then, a plethora of research has been undertaken in scheduling (Calinescu and Tongngam, 2011), (T. Tonoyan, 2013), (Fan, Zhang, Feng, Zhang and Ren, 2012), (Halldórsson and Mitra, 2012), as well as topology control (Lou, Tan, Wang and Lau, 2012), (Bodlaender, Halldórsson and Mitra, 2013) under the SINR model.

In (Halldórsson, Holzer, Mitra, and Wattenhofer, 2013), the authors explicitly investigate the power of the non-uniform transmission power. On the other hand, in (Avin, Lotker, Pasquale, and Pignolet, 2009) valuable information is provided on the employment of uniform transmission power. This is close to our work, with the difference that we aim to show different cases of uniform transmission powers utilization under the SINR model. In (Whitehouse, Woo, Jiang, Polastre and Culler, 2005), the authors consider a scheme of collisions and not failures that make explicit the utilization of the capture.

Furthermore, we provide the reader with some early works regarding throughput increase in wireless networks. In (Biswas and Morris, 2005),, the authors propose a routing and MAC layer protocol, which aims to the maximization of throughput. Also, a scheme that surpasses graph-based models is suggested in (Katti, Rahul, Hu, Katabi, Medard, and Crowcroft, 2006).

3 PROMISSING EXAMPLES OF UNIFORM TRANSMISSION POWER

Initially we assume that the nodes are randomly distributed on a unit plane. Moscibroda, Wattenhoffer and Weber, (2006) showed that doubling the throughput is feasible when we employ non-uniform transmission powers in a 1-D setting. We consider a 2-D scenario where devices transmit with uniform transmission powers. We consider a network of devices, where a transmission from a device is successful if the receiver can decode the message. This occurs when $\frac{P}{I+N} \geq \beta$, where P is the signal strength, I is the sum of interferences from other devices and N is the ambient noise. Denote β as the hardware-dependent ratio.

Furthermore, under the physical model of propagation, the signal strength P is modeled as a polynomially decreasing function depending on distance between the sender-receiver pair of devices. Denote this as $d(x_s, x_r)$ and the aforementioned function as $\frac{1}{d(x_s,x_r)^{\alpha}}$ where α is the path-loss exponent ranging from 2 to 6 according to the setting of the network (e.g outdoor, indoor).

We assume that the path loss exponent α = 3, the SINR threshold β = 3 and the background noise N = 10nW. Note that the values above are reasonable for practical wireless sensor scenarios, as presented by Son, Krishnamachari, and Heidemann, (2006). We denote $\beta(x_i, x_j)$ as the SINR ratio of node x_i when node x_j is transmitting. Hence the power of node x_j is the signal and the powers of the other nodes transmitting simultaneously are considered as interference. Obviously, a transmission is successful if $\beta(x_i, x_j) \geq \beta$.

Consider the example that is given in figure 1. We observe that the distances between the transmitting and the interfering nodes are greater by approximately a factor of 2. This is that the interference distance is twice as great as the transmitting distance.

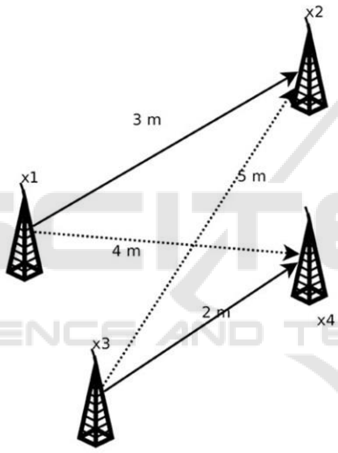

Figure 1: Nodes Transmitting Simultaneously with heterogeneous distances.

If we obtain the SINR values of the two transmission pairs we have the following:

$$\beta(x_3, x_4) = \frac{1000\mu W(2m)^3}{0.01\mu W + 1000\mu W/(4m)^3} \approx 8$$

and

$$\beta(x_1, x_2) = \frac{1000\mu W/(3m)^3}{0.01\mu W + 1000\mu W(5m)^3} \approx 4.5.$$

This shows that both messages transmitted go through in the case of simultaneous transmission. The values exceeding the SINR threshold hold even if nodes transmit with the minimum transmission power. Note that using any graph-based approach trying to send the two messages in parallel will fail because, intuitively, the medium between the two receivers can only be used once per time slot.

4 MULTIPLE NODE INTERFERENCE

The main issue with the utilization of the SINR model is the fact that it can get very complicated, constituting it intractable in terms of the protocol designer. In known network topologies, transmission power increase results in node degree increase, which implicitly means that the number of interferers increases as well. This may assist in the decrease of the packets decoded in the network; hence, a decrease in the PRR. Y. Gao, J. C. Hou, and H. Nguyen, (2008), p.3 introduce the term "interfering node", which is given by (1).

$$\frac{p_t(i) d_{i,j}^{-\alpha}}{N + p_t(k) d_{k,j}^{-\alpha}} < \beta \qquad (1)$$

Where $d_{i,j}$ is the distance between the sender i and the receiver j. Also, $d_{k,j}$ is the distance between the interfering node k and the receiver j. This essentially provides the node, whose interference results in the packet to be dropped by the receiver. The authors also provide the term interference degree, which they show that it might not be minimized by using the minimal transmission power assignment.

Note that a node can be interfering with the transmission of packet and the packet may still be received. Hence, interference degree is the number of nodes that collide or interfere with a transmission that may result in a successful transmission or not.

Following the interference degree, it is useful to provide the reader with some notes on the potential number of interferers. Earlier in the paper, we assumed that the nodes are randomly distributed; hence, the number of interferers is a random variable. Nodes that are receiving in slot s-1 are transmitting in slot s, thus, interfering with nodes receiving in slot s. We refer the MAC layer slots as slots. We use the work of Vakil and Liang, (2006), p.4, to indicate that the number of interferers is given by (2)

$$N_{I_r}[s] = \sum_{i=1}^{N_p[s]} N_{I_r}^i[s] \qquad (2)$$

where $N_{I_r}^i[s]$ is the number of nodes within the transmission range r of node i, which have been receiving in slot s and transmitting in the current slot. Also, $N_p[s]$ is the number of permissible sources – transmission ranges - in slot s. There is a difficulty in obtaining the number of interferers, since the calculation of inter-node distance is required and is quite difficult to obtain accurately. The parameter, which can be utilized in order to obtain the distance, is the Received Signal Strength Indicator (RSSI) value (Xu, Liu, Lang, Zhang and Wang, 2010), which may differ significantly from its actual value if the two nodes are not within Line-Of-Sight.

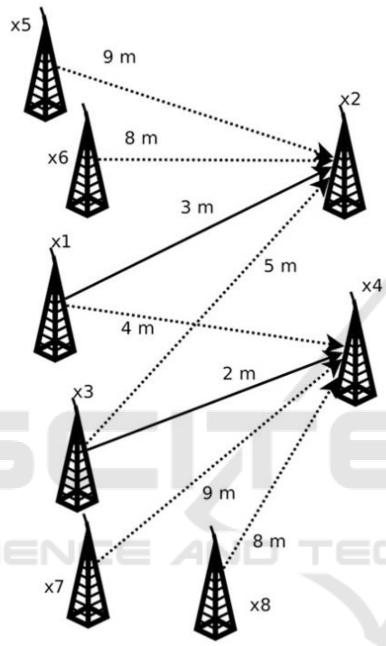

Figure 2: Multiple Nodes Transmitting Simultaneously with heterogeneous distances

We will continue our examples shown in the previous section of the paper, in order to show a case where the packets in the presence of multiple interfering nodes get decoded simultaneously. We have to mention that the intuitive action of the transmitting nodes in figure 2 is to reduce their transmission power in order to minimize the interfering nodes; hence, to increase the probability of decoding the packet successfully. However, the case we examine in the particular figure shows that even with a high transmission power, simultaneous reception of the packets is feasible, provided that the interfering nodes are at a quite larger distance than the transmitter-receiver pair. Note that all the nodes are transmitting with transmission power of 0dB. Specifically, the SINR ratio between nodes x1 and x2 with nodes x5, x6 interfering is

$$\beta(x_1, x_2) = \frac{1000\mu W/(3m)^3}{0.01\mu W + \frac{1000\mu W}{(4m)^3} + \frac{1000\mu W}{(8m)^3} + \frac{1000\mu W}{(9m)^3}} \approx 3.6,$$

which is higher than the SINR reception threshold. Similarly, for nodes x3, x4 when nodes x7 and x8 are interfering the SINR is

$$\beta(x_3, x_4) = \frac{1000\mu W/(3m)^3}{0.01\mu W + \frac{1000\mu W}{(4m)^3} + \frac{1000\mu W}{(8m)^3} + \frac{1000\mu W}{(9m)^3}} \approx 6.6.$$

Hence the packet is received successfully.

5 EXPERIMENTAL RESULTS

We decided to put some of our examples to a test reflecting some of the examples we carried out. We are considering a network of 15 nodes running for 30 minutes on the Indriya testbed (M. Doddavenkatappa, M. C. Chan, and A. L. Ananda, 2012). Note that there will be 108000 messages transmitted to all the nodes in the network, since every node is transmitting 4 packets per second. The devices in Indriya are employed with the Chipcon CC2420 radio, which uses the modulation and encoding specified by the IEEE802.15.4 standard.

We carefully selected two scenarios; one, where the nodes are connected but in a sparse manner and another that the nodes are in a dense area. We employed a form of synchronization, where the nodes transmit at the same time. Note that the transmission power, with which the nodes transmit is the maximum, 0 dB. The metric we utilize is the Packet Reception Ratio (PRR) and the number of successful receptions on the network. First, though, we provide the reader with the relationship between the SINR and the PRR.

SINR is the Signal-to-Interference-plus-Noise Ratio (SINR) of the transmission from node k to node j, which we denote as $\gamma_{k,j}$, which is given by

$$\gamma_{k,j} = \frac{h_{k,j} p_k}{\sum_{t \neq k, t \neq j} p_t h_{t,j} + N_0} \quad (3)$$

where $h_{t,j}$ is the channel gain between the interfering node t of node j. The Bit-Error-Rate (BER) for the CC2420 (Fu, Sha, Hackmann and Lu, 2012, p. 3), which we denote as ξ is

$$\xi_{k,j} = \frac{1}{2}\left(1 - \sqrt{\frac{\gamma_{k,j}}{1 + \gamma_{k,j}}}\right) \qquad (4)$$

and finally, for any link $(k, j), k, j \in N$, $PRR_{k,j}$ denote as $P_{k,j}$ - can be expressed by

$$P_{k,j} = \left(1 - \xi_{k,j}\right)^{l} \qquad (5)$$

where l is the packet length in bits. As dictated in Zhao and Govindan (2003), at the physical layer, packet reception experiences variability by the existence of a grey area within the communication range of a node. Receiving nodes in this grey area are susceptible to unstable packet reception. Furthermore, the grey area is almost a third of the communication range in certain environments. The grey area also exhibits temporal packet reception variation.

Physical layer coding schemes exist capable of masking some of the variability of packet reception. The 802.15.4 standard uses a 32:4 DSSS chip-to-bit encoding. Because the CC2420 uses soft chip decision, there's no real concept of a "bit error." Instead, it effectively calculates the closeness of each chip to 0 and 1 and then chooses the symbol sequence which is closest to the soft chip decisions.

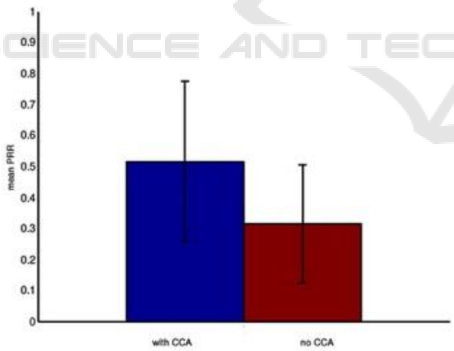

Figure 3: Mean PRR with and without CCA of dense topology

In most scenarios a high SINR means high PRR. We performed two experiments; in the first setting the nodes use the Clear Channel Assessment (CCA), in order to sense the channel before they proceed to a transmission of a packet. In the case that the channel is busy, the node performs an exponential back-off and attempts to transmit again. In the second scenario, using the same configuration of nodes, CCA is being disabled. Our intuition is that we will find a difference in the performance of the two settings in the sparse case. As for the dense configuration, we believe that the CCA enabled setting will outperform the CCA-disabled one. This is due to the examples in the previous section, that the nearest interferer will block the transmission.

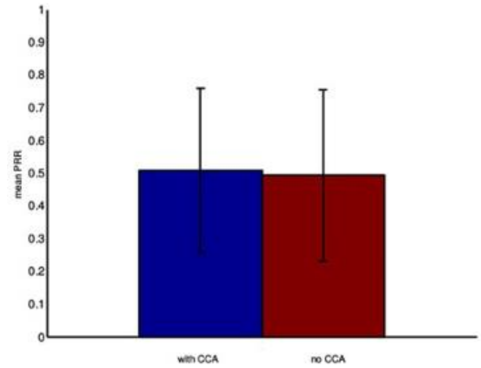

Figure 4: Mean PRR with and without CCA of sparse topology

In figure 3, we observe that for the dense scenario, disabling the CCA significantly affects performance. In fact, the difference between the CCA- enabled and CCA-disabled is approximately 20%. Furthermore, we investigated the number of the received messages received by all nodes in the network configuration. Our findings show that the CCA-enabled setting achieved 15,3% more messages received than the CCA-disabled setting. This is natural since, the messages transmitted by the CCA-disabled network are being dropped, since the channel is not sensed first, due to the density of the configuration.

Thereafter, we studied the performance of the same two settings for a sparser configuration, where the interferers have a greater distance from the receivers. In figure 4 we can see the mean PRR obtained for both settings. We note that the mean PRR is similar, which does not give us enough information on which settings accomplishes the best performance.

Table 1: Received messages of sparse topology with/without CCA

Configuration	**Received Messages**
With CCA	54864
No CCA	53244

Table 1 provides information of the received messages across the network. We observe that the number of the received messages of the configuration with the CCA disabled reaches the number of messages of the CCA-enabled one. This is due to the fact that when CCA is disabled, provided the sparsity of the configuration, interferers and transmitters pass messages at the same time, without performing a backoff, which may result in packet drop. On the other hand, even in the sparse configuration, nodes sense the channel's state first; hence they delay in the transmission of their packets.

6 CONCLUSIONS

In this paper we showed that utilizing uniform transmission powers may result in increase of PRR. This is dependent on the distance between the receiver and the interferer. We studied two settings, one with CCA enabled and the other with CCA disabled. We have seen that in a sparse configuration, using the CCA-disabled setting results in the network reaching the quality of messages reception of the CCA-enabled setting; thus, exhibiting a similar PRR. On the other hand, in a dense configuration, the CCA-enabled setting outperforms the one where CCA is disabled.

The use of the aforementioned results implies the necessity of spatiotemporal optimization and stability of wireless sensor networks. That is, WSN power control optimization methods may employ the careful selection of receivers to indicate whether a network should use uniform or non-uniform transmission power settings in specific regions. Furthermore, depending on the network density as well as the network neighbor and interference degrees, the network protocol designers, may find that CCA is a holding back factor of the network throughput increase. This may be valid in outdoor topologies where the signal is not affected by factors, such as Wi-Fi devices (Wu, Stankovic, He and Lin, 2008).

At this point, we have to mention it would be interesting to experiment with nodes when distances are fixed, according to the examples discussed previously. Furthermore, since the Indriya testbed is spread across different rooms, another interesting experiment would be to test the topological configurations under Line-Of-Sight, where the path loss exponent does not fluctuate. These experiments may provide us with useful insight regarding the PRR and rate of transmission.

Finally, this approach may indicate the fact that interference may not be high enough to require lowering the transmission power level of a node, even if the transmission power used is high. This may give a helpful insight on the behavior of the network PRR in a two-hop neighborhood.

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