Simulation of Simulcast for Packet Transmission using MATLAB
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Abstract—In a wireless LAN, received signal strength indication (RSSI) varies in propagation loss, fading, and interference levels depending on the channel. In a single input, single output (SISO) scenario, a transmitter can use redundancy to overcome channel impairments such as fading. However, in a single input, multiple outputs (SIMO) scenario, there is one transmitter and multiple receivers sharing the same channel. The redundancy transmitted for receivers with lower signal to noise ratio (SNR) is inefficient when other receiving nodes with higher SNR do not require the adaptive signaling used by the transmitter. A paper written on the research done at the University of Florida titled, “Simulcast Packet Transmission in Ad Hoc Networks” by Jung and Shea in 2005 compares the throughput of a unicast scenario to two different simulcast situations. In most situations, simulcasting is more efficient than unicasting from the paper studied [1]. Our group first verifies the throughput improvement using simulcast over unicast as described in the paper. Afterwards, we investigate how changing parameters, according to the network conditions, affect the performance of a simulcasting network.

Index Terms—MATLAB, Ad hoc networks, multicast signaling, nonuniform modulation, simulcasting, Quadrature phase shift keying, unicast.

I. INTRODUCTION

Nodes in an adhoc network differ in their ability to demodulate transmission because of the propagation and interference. In unicast network, a transmitter can use techniques such as spectral estimation to know the transmit power to send to each node. The more information the transmitter knows about the current transmission medium, the better the network efficiency. Nodes that require higher transmit power to receive packets from the base are known as less-capable nodes. Nodes which need a lesser power are known as more capable nodes. Simulcasting is a technique wherein more-capable nodes demodulate a non uniform Quadrature Phase-Shift Keying (QPSK) constellation to receive packets whereas the less-capable nodes demodulate the Binary Phase-Shift Keying (BPSK) constellation to receive packets transmitted to them by the same transmitter. This reduces the number of transmissions a transmitter has to attempt to transmit the same number of packets as compared to a unicast network. This scheme, in many cases, greatly improves the efficiency of the network [1].

To optimize simulcasting, higher-layer protocols and parameters such as packet selection, routing, collision resolution algorithm, attempt rate and phase angle need to be appropriately designed. Changing these parameters affect network performance characteristics such as network connectivity, route length, link-to-link average throughput and end-to-end average throughput. This study uses a non-uniform QPSK. The effect of varying the QPSK modulation phase angle, as done in other studies[1], is verified. The medium access control protocol chosen for the study is Slotted ALOHA in which packet arrival is modeled using Bernoulli random process [2]. Multiple access is provided by Slotted ALOHA with a routing algorithm modified to support simulcasting ability. The packet selection is adjusted for simulcasting as well. Utilizing a nonuniform QPSK simulation can demonstrate the effect that simulcasting has on link-to-link throughput, end-to-end throughput, and network connectivity [1].

II. SIMULATION DESIGN

The simulation is done by generating random topologies of a 20-node adhoc network. This network uses a Slotted ALOHA protocol because the protocol’s simplicity and popularity as a Medium Access Control (MAC) protocol [3]. The simulated adhoc network’s Slotted ALOHA protocol is modified with a geometric backoff algorithm. The physical layer is modeled using Orthogonal Frequency-Division Multiplexing (OFDM). With the nonuniform QPSK modulation used, symbols with a high in-phase (I) coordinate would be demodulated by the less-capable radios. Simultaneously, the same constellation has symbols with a low quadrature phase (Q) coordinate which can only be demodulated by the more-capable radios. A phase angle (θ) determines the difference in power between I channel and Q channel available for less capable and more capable radios respectively. The phase angle (θ) is determined as an inverse tangent of the symbol’s I and Q coordinates. A previous study[1] uses θ = 19.25° for the phase angle in simulations. The simulcasting technique is in effect transmitting BPSK to two different nodes simultaneously by utilizing a nonuniform QPSK modulation.

A. Physical Layer Modeling

The Physical layer modeling includes transmitter modeling, channel modeling, and receiver modeling. The modulation
used for each message is BPSK [1]. In the case of simulcast, a basic message for a less capable node is coded with an addition message which are scaled by \( \cos(\theta) \) and \( \sin(\theta) \) respectively [1]. Consequently, this process converts the BPSK to a non-uniform QPSK for the offset angle of \( \theta \). At the transmitter side, the transmission process is modeled using OFDM system. The flow process including forward error correction coding to add the capability to correct up to ten bits of error out of 1000 bits of data [1], channel coding, and inverse FFT are performed to produce the analog signal necessary to send to the channel. In the channel modeling, additive white Gaussian channel is used with path loss exponent of 4 [1]. The mount of noise added to the signal results a bit error rate of \( 1 \times 10^{-4} \) at the maximum transmission distance of 1 km. Finally, the receiver extracts the basic message and additional message by using FFT. The real and imaginary signals after FFT are the basic message and the additional message respectively. In the case of unicast, the additional message is filled with zeros. Upon receiving the messages, error detection is performed to verify the integrity of the message.

B. MAC & Network Modeling

1) Routing: For the simulations in our project a modified minimum hop algorithm is used. More capable links are given higher weight then less capable links, thus the minimum route with maximum more capable links is chosen.

2) Slotted ALOHA: The network uses Slotted ALOHA network protocol to implement the Multiple Access scheme among the nodes. The nodes are allowed to transmit a packet only at the start of a slotted time interval. A node tries to transmit a packet in the very next slot after its arrival in case the node does not have any other packet in the queue before it. However, if the packet suffers a collision or transmission failure due to channel errors, it waits for a random number of time slots and then attempts a retransmission of the packet with a retransmission probability \( Pr \). The distribution of the random number of waiting time slots for which the node is in back-off state follows a Geometric Distribution [4]. Maximum number of retries for each packet is 4 after which the packet is dropped. As compared to a unicast network, the nodes in the simulcast network need to keep account of the state due to both the packets related events. An example situation is the arrival of a new packet 'K which can be sent on a more capable link when the node is already in a back-off state due to an earlier packet (K-1)s collision. In this situation, node continues to wait in the back-off state due to the failed (K-1)s transmission attempt and schedule the transmission of the new packet K along with the older packet (K-1). Similar, dropping of only one packet after reaching the maximum number of retries does not bring the node out of backoff state. In conclusion, we can say that if a node observes two events due to both the packets which may affect its state, it chooses to change its state based on the event which needs the node to spend more time in the back-off state. The attempt rate of the node can be controlled using retransmission probability and the arrival rate of the packets which follows the Bernoulli distribution.

3) Packet Selection: The packet selection algorithm followed by a node is as following:

   a. Give priority to the locally generated packets.
   b. Sort out the packets depending upon if they are forwarding packets or locally generated packets.
   c. Check the next hop destination of the packet.
   d. If the transmitting node has only a unicast link to the destination, then schedule the packet in the next slot.
   e. If the transmitting node has a simulcast link to the destination, schedule another packet destined to a node having only a unicast link with the transmitting node. This is the most efficient case wherein we schedule one packet each for a simulcast link and a unicast link.
   f. If there is no packet available for a node having a unicast link with the transmitting node, select another packet which can be sent on the simulcast link. Thus, in this case, we schedule two simulcast link capable packets.

C. Topology Generation

Random topologies are generated using two independent random variables for the X and Y direction. The links between the nodes are decided by the distance between nodes. Equation 1 shows the maximum distance for a more capable link, and equation 2 for a less capable link, Where \( d_U \) is the maximum distance between two nodes to form a link in unicast transmission[1].

\[
d_m = d_U[\cos(\theta)]^{\frac{2}{\pi}}
\]

\[
d_l = d_U[\sin(\theta)]^{\frac{2}{\pi}}
\]

To verify the results in [1] the same parameters are used for topology generation. The area used in this report is \( 1 \text{km} \times 1 \text{km} \) and \( d_U \) is 381 m. Figure 3 illustrates random topology.

III. SIMULATION TESTS

In this section the outline of the testing procedure is detailed. First a base study verifying the findings in [1] is performed. Then an additional study with the goal of improving End-to-End throughput is done.
A. Base Study

In the base study the packet destinations were generated using a Poisson distribution. In the Poisson distribution most of the packets have a farther destination. The parameter \( \lambda \) is calculated by equation (3) [5].

\[
\lambda = \frac{4}{\cos(\theta) \pi}
\]

Equation (4) shows the probability of choosing a destination of \( k \) hops. It can be seen as \( \theta \) increases the average number of hops also increase.

\[
P[Hops = k] = p_k = \frac{\lambda^k}{k!} e^{-\lambda} \quad k = 0, 1, 2, \ldots
\]

For the tests in this simulation the average link-to-link throughput as-well as the end-to-end throughput will be measured. Throughput will be calculated by using equation (5).

\[
Throughput = \frac{\# \text{ of Successful Packets}}{\# \text{ Slots}}
\]

1) Network Degree: The network degree vs. offset angle \( \theta \) is analyzed and compared with the findings in [1].

2) Nodes with more capable links: As \( \theta \) is varied the number of nodes with more capable links changes. A test is performed to verify that it increases logarithmically as \( \theta \) increases.

3) Average Link-to-Link Throughput: This test verifies that the Average Link-to-Link Throughput is improved in simulcast vs. unicast transmission. Simulcast transmission is done with nonuniform QPSK with offset angle \( \theta = 25^\circ \).

4) Maximum Average Link-to-Link Throughput: The maximum Average Link-to-link Throughput across different attempt rates is found for different values of \( \theta \) and compared.

B. Additional Study

In the additional study, we modify the distribution of number of hops for a packet using three different models including uniform and geometric. In the uniform distribution of hops, a packet has an equal probability to be assigned for different number of hops. In the geometric distribution of number of hops, its parameter is chosen in such a way that most of the packets are assigned to nearby destinations [5]. The parameter \( \alpha \) is given by equation (6).

\[
\alpha = \frac{\pi \times d_U^2}{Area}
\]

Equation (7) shows the probability of choosing a destination of \( k \) hops [6]. It can be seen as \( k \) increases the probability decreases.

\[
P[Hops = k] = p_k = (1 - \alpha)^k \alpha \quad k = 0, 1, 2, \ldots
\]

Compared to the empirical distribution used in [1] or Section III-A, these three models fit better for the purpose of verifying the end-to-end throughput gain from the simulcast signaling.

Furthermore, the channel of the simulation was modified so that the BER of \( 1 \times 10^{-4} \) occurred at the distance of 381 meters rather than 1 km[1]. In this case, the degradation or lost of connectivity, which caused by the simulcast signaling, can be studied. Consequently, the result of this study will be more accurate compared to the Section III-A.

Finally, the number of nodes was increased to 30 while maintaining the same topology area in order to study how simulcast signaling behaved in a higher traffic network.

IV. RESULTS

The performance of the simulation detailed in Section II is analyzed and compared with the results in [1]. Additional Studies which are not considered in [1] while investigated and analyzed. Possible improvements to which have been stated in Section II are be studied as-well.

A. Base Study

The results of the test performed in Section III-A1 are as expected. Figure 4 shows the results of the simulation. The results closely match Figure 7 in the reference paper [1]. There are minor variations from the two figures, but this is to be expected due to the difference in topologies used. The important is that both figures follow the same trend.

The results of the test performed in Section III-A2 are as expected. Figure 5 shows the results of the simulation. The results closely match Figure 9 in the reference paper [1].
Fig. 4. Plot of Network Degree v. Offset angle $\theta$

Fig. 5. Plot of $R_m$ (Ratio of more capable nodes to total nodes) v. Offset angle $\theta$

Fig. 6. Link Throughput for unicasting and simulcasting with nonuniform QPSK with offset angle $\theta = 25^\circ$

Fig. 7. Maximum (over all attempt rates) link throughput for simulcasting with nonuniform QPSK as a function of offset angle $\theta$. Packets are generated using a Poisson distribution in number of hops.

$p_m(\theta) = \frac{\pi [d_m(\theta)]^2}{\text{Area}}$  

$R_m(\theta) = 1 - [1 - p_m(\theta)]^{N-1}$

These results also follow the same trend as the theoretical formula (9) for the more capable node ratio, where $p_m$ is the probability of a more capable link and $N = 15$ (Number of nodes) [1].

Figure 6 shows the results from the test described in Section III-A3. The throughput for unicast and simulcast peaks at an average attempt rate of 0.267 and 0.293 respectively. The efficiency for the simulcasting technique is proven in the simulation by simulcasting peaking in link-to-link throughput as high as 0.116. The unicasting link-to-link throughput peaks at 0.0741.

The Maximum Average Link Throughput is shown in Figure 7. The reference paper [1] states that the simulcast throughput for simulcast transmission should follow the trend in equation (10).

$S_S = S_U [1 + R_m(\theta)]$  

The simulation results follow the expected trend for the most part, but the high gains due to simulcasting found in [1] could not be replicated consistently.
Figure 8 shows the maximum average end-to-end throughput with packets that are generated using a Poisson Probability Distribution shown in (4) and obtained from [6]. The end-to-end throughput in Figure 8 closely follows the results in from the reference paper [1]. The simulation results peak at $\theta = 19.25^\circ$. In the reference paper [1], end-to-end throughput peaks at $\theta = 25^\circ$.

B. Additional Study

In the geometric distribution of number of hops study described in Section III-B, the results showed an increase in performance to the Poisson distribution results from Section IV-A. Figure 9 shows the maximum average link throughput. As $\theta$ increases the throughput increases logarithmically opposed to linearly in the Poisson distribution case. Figure 10 shows the maximum average end-to-end throughput with packets that are generated using a geometric probability distribution shown in equation (7) obtained from [6]. The throughput is higher than expected, peaking at 11% for the end-to-end throughput. This high throughput could be explained from the randomly generated geometric distribution routes having fewer node hops.

In the uniform distribution of number of hops study described in Section III-B, each packet arrives at the network has equal probability of having different number of hops. In this case, the network packets are evenly distribution in hops to generate an average traffic. From Figure 11, it’s clear that the link-to-link throughput increases when simulcast is enable ($\theta > 0^\circ$). In particular, the link-to-link throughput nearly doubles at $\theta = 19.25^\circ$. Overall, the link throughput gain follows the same trend in the base study. Similarly, the end-to-end throughput (Figure 12) of the network shows the same performance gain when simulcast is enable. Therefore, simulcast signaling has an advantage over unicast signaling in the ad-hoc network of which the number of hops has a uniform distribution.

As shown in Figure 13, simulcast signaling improved the overall link-to-link throughput as expected. However, in Figure 14, the maximum throughput occurred at $\theta = 5^\circ$ rather than $\theta = 19.25^\circ$ in Section IV-A. This result caused by the modified channel showed that simulcast signal could still improve the overall throughput in a lower SNR channel.

As shown in Figure 15, simulcast signaling improved the overall link-to-link throughput even when the number of nodes was doubled to 30. Figure 16 shows that the end-to-end throughput followed the same trend as when the number of nodes was 15.
Fig. 11. Maximum (over all attempt rates) link throughput for simulcasting with nonuniform QPSK as a function of offset angle $\theta$. Packets are generated using a uniform distribution in number of hops.

Fig. 12. Maximum (over all attempt rates) end-to-end throughput for simulcasting with nonuniform QPSK as a function of offset angle $\theta$. Packets are generated using a uniform distribution in number of hops.

Fig. 13. Maximum (over all attempt rates) link throughput for simulcasting with nonuniform QPSK as a function of offset angle $\theta$. Packets are generated using a Poisson distribution in number of hops, and the maximum distance of 381 meters for a BER of $1 \times 10^{-4}$.

Fig. 14. Maximum (over all attempt rates) end-to-end throughput for simulcasting with nonuniform QPSK as a function of offset angle $\theta$. Packets are generated using a Poisson distribution in number of hops, and the maximum distance of 381 meters for a BER of $1 \times 10^{-4}$.

V. CONCLUSION

In Section IV-B the findings in the reference paper [1] were verified. The findings in the paper follow the same trends. Further tests are done and the results are presented in IV-A. It is found that a geometric distribution in hops results in higher average link throughput and maximum average end-to-end throughput. This is due to the lower average number of hops in a route, thus the probability of a successful end-to-end transmission is increased.

REFERENCES

Fig. 15. Maximum (over all attempt rates) link throughput for simulcasting with nonuniform QPSK as a function of offset angle $\theta$. Packets are generated using a Poisson distribution in number of hops, and the number of nodes is increased to 30.

Fig. 16. Maximum (over all attempt rates) end-to-end throughput for simulcasting with nonuniform QPSK as a function of offset angle $\theta$. Packets are generated using a Poisson distribution in number of hops, and the number of nodes is increased to 30.