Distributed Beamforming Feasibility Testing

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***Abstract*— Distributed beamforming is a communication technique in which multiple sources transmit the same message signal at the same time and the phase of the transmitted signal is controlled in a way that the signals have constructive interference at the receiver. This paper presents a review of related work focused on implementing distributed beamforming using various techniques, also it measures and compares the amplitude as well as RSSI (Receiver Signal Strength Indicator) of the received signal for three different cases at different points in the particular area (known as grid) with respect to the reference node. The three different cases are; without beamforming (SISO), with beamforming (MISO), and with distributed beamforming (MISO).**

Keywords
Beamforming, Distributed Beamforming, Phase Synchronization, Clock Synchronization

I. Introduction

With recent advancements in the wireless communication technology, it is necessary to have power efficient systems with minimum area. Distributed beamforming provides enhanced energy efficiency of communication with improved communication range as well as reduced interference. With distributed beamforming, it is possible to have a larger network with limited transmit power to achieve the same signal strength at the receiver.

Beamforming is a RF management technique in which an access point uses multiple antennas to send out the same signal to the intended receiver. The phases of transmitted signals are aligned in a way that at the receiver it combines in constructive interference resulting in more power in the direction of receiving antenna compared to other directions. This provide less interference in direction other than direction of the intended receiver. There are many feedback systems which are implemented in order to determine the best path to reach the intended receiver in the best possible way. The transmitter will adjust the transmitting signals from the feedback and will determine the best signal path to reach the receiver.

Distributed beamforming refers to the term where two or more separate transmitters with same message signal connects with one another to make an array of antennas transmitting towards an intended receiver. The primary concept of distributed beamforming is that each transmitter with the same message signal with phase aligned carriers and these transmissions merge with one another to form a constructive interference at the intended receiver.

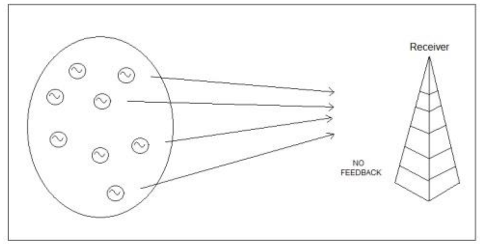

Figure 1 Distributed Beamforming [1]

In distributed beamforming, multiple node will transmit same signal to the receiver, to do it successfully all transmitters should transmit at the same time with same carrier frequency and control their phases to get constructive signal at receiver. To achieve these objective a system is required for sharing the information related to timing and carrier synchronization.

Importance of distributed beamforming:
In distributed beamforming, the signal that is transmitted is highly unidirectional and therefore less signal is transmitted in unintended direction. Also using more number of transmitters which send same message signal, the transmitter power is reduced. Thus making the system more power efficient and also reducing the cost.

In this paper, our basic aim is to test the feasibility of distributed beamforming by measuring the performance of distributed beamforming against similar technologies such as with beamforming and without beamforming. To do so we will measure the amplitude and received signal strength indicator (RSSI) value at the receiver end and with another measurement node, we will measure amplitude and RSSI around the transmitter and receiver in three different cases.

1. Case without Beamforming (SISO).
   SISO Systems or the single input single output communication systems are the simplest form of the communication system where there is a transmitting antenna at the source and a receiving antenna at the destination.
2. Case with Beamforming (MISO).
   MISO (Multiple Input and Single Output) is a technique of RF wireless communication system in which there are multiple transmitting antennas at the source and single receiving antenna similar to the SIMO system but at the destination, receiver has single antenna. In our case, there are two transmitting

antenna at one node and one receiving antenna at receiver node.

3. Case with Distributed Beamforming (MISO).
   This case is similar to the 'case with beamforming' having just one difference. Here, multiple nodes with multiple antennas form an array of transmitter which transmits data to receiver. In our case, two nodes each with one antenna and one receiving antenna at the receiver.

All these experiments will be done on Wireless Open Access Research Platform (WARP) and we will use the WARP Lab reference provided by the WARP team. We will compare the amplitude and the received signal strength at the receiver end so that we can differentiate how effective and efficient is the distributed beamforming. For the beamforming, it is important to have phase and clock synchronization at the transmitting side. In this experiment, phase synchronization is achieved manually after observing received signal in MATLAB. In case (2), both the transmitters share one CPU so there is no clock synchronization required, while for case (3) due to two different transmitting nodes clock synchronization is required, so one node will provide clock reference for second node in order to achieve clock synchronization triggering both the transmitters at the same time to transmit data that we plan to use the available trigger manger on WARP board. Heat-Map of the respective measurements in MATLAB can give us an idea about the signal footprints.

This paper consist of six sections. Section II gives us an idea about related work done in beamforming and distributed beamforming. In Section III, we show implementation of our work and expected results. In Section IV, details of required resources for experiments. Section V will give us an idea about what work we have accomplished and the remaining work, and Section VI describes deliverables and role of team members.

II. Related Work

1. Distributed Carrier Synchronization: The goal here is to achieve frequency synchronization, phase synchronization and time synchronization [2].

1.1. Full-Feedback Closed-Loop Synchronization: Master-slave algorithm is used to achieve carrier frequency synchronization, by assigning the destination node as the Master. The closed loop protocol is used to determine the phase offset between the destination and the source node [3].

1.2. One-Bit Feedback Closed-Loop Synchronization: The basic idea here is that the carrier phase of the source node is adjusted arbitrarily. Each source node adjusts its carrier phase randomly. The source node acts like a distributed beam former and will transmit simultaneously to the receiver. The receiver will then calculate the SNR and will send a feedback signal to the source to measure the quality of the SNR received as compared to the previous SNR [2].

1.3. Master-Slave Open-Loop Synchronization: Here the interaction between the source nodes is higher than the interaction between the source and destination. Here one of the source node is assigned as master and rest of them as slaves. The master node will transmit a beacon signal to all slave nodes so that the slaves calculate its frequency offset for frequency synchronization [4]. Also, a closed loop [3] is used between all the source nodes to achieve phase synchronization. After synchronization is done, the source node can then calculate its complex channel gain and transmit to the destination as a distributed beam former.

1.4. Round-Trip Open-Loop Synchronization: This method is known as round-trip open-loop synchronization because it is based on round-trip propagation delay through multi-hop chain of source nodes. The basic idea here is that, if we measure the total phase shift of the unmodulated beacon 'bounced' around a clockwise circuit, it is same as the total phase shift obtained when an unmodulated beacon 'bounced' around counter clockwise circuit when channels are reciprocal [5,6].

2. Beam Patterns for Randomly Placed Sources: The source nodes (sensors) that we used must have an ability to transmit information over long distances with high efficiency and thus directional antennas are used. Here adaptive beamforming is used. When we are given the number of antenna elements at the sensor nodes (transmitter/receiver), each node can then be used to transmit/receive information to/from any direction intended [7].

3. Information Sharing Among Beamforming Nodes: In distributed beam forming, before the information is sent, it is first shared amongst the source nodes. Recently a scheme was proposed with higher-throughput space division information sharing strategy, in which the independent information from all the K master source nodes was simultaneously broadcasted to the pool of non-master source nodes. For the message of the kth master source node to coherently combine at the kth destination the N non-master source node should simultaneously beam form to the kth destination node [2].

4. Multi user beam forming: The research on this by [8] designs, evaluates, realizes Argos the first reported base station architecture that simultaneously can serve many terminals through multi user beam forming, with large number of antennas to have better efficiency an d scalability this design is capable of handling 64 antennas with serving 15 clients simultaneously. They demonstrate that by scaling from 1 to 64 antennas the design ca achieve up to 6.7 fold capacity gains while using just 1/64th of transmitter power.

5. Beamforming based on channel estimation by using RSSI measurements: [10] this paper explains how to achieve beamforming benefits by using RSSI measurements at the receiver along with an intelligent estimation methodology at the transmitter. Here, experiments are performed in indoor office scenario with commercial Wi-Fi clients and it also shows how distributed beamforming scheme helps to achieve performance improvements across diverse scenarios.

None of the papers include comparisons of amplitude and RSSI value of received message signal for different technologies. Our paper provides clear comparison between amplitude and RSSI of the received message signal for three different cases at different points in the grid with respect to the reference node.

III. Implementation

As mentioned, there will be three different cases.

1. Case without Beamforming (SISO)
2. Case with Beamforming (MISO)
3. Case with Distributed Beamforming (MISO)

Case Without beamforming (SISO):
The proposed design for this case is implemented on WARP Lab7, transmitter node will ping the receiver node and third node (Rm) will measure the RSSI value for that channel at different locations on grid as per the proposed setup. The size if the grid is 5×5.

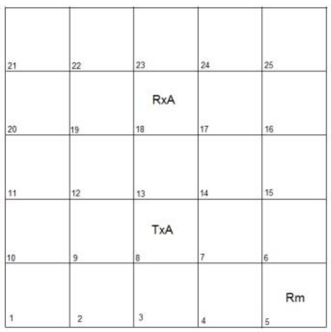

Figure 2 Proposed Experimental Setup First Case

Case with Beamforming (MISO):
In this case, for phase calibration we will divide reference signal into two parts. TxA will have the first half of the signal followed by all zeros in the second half and TxB will have first half of zero followed by the reference signal in the second half.

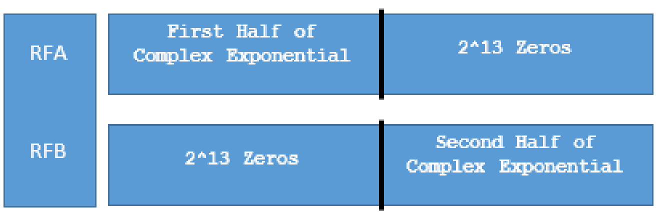

Figure 3Phase Calibration Signal [11]

The proposed design for this case is implemented using WARP lab reference design. Here, a transmitter will have two antennas that will be sending same message signal to the receiver node containing one antenna. The third node (Rm) will measure the amplitude and RSSI value for the transmitted signal at different locations in the grid [11]. The size if the grid is 5×5.

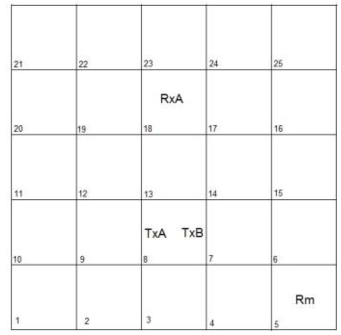

Figure 4 Proposed Experimental Setup Second Case

Case with Distributed Beamforming (MISO):
In this case, we are going to test the feasibility of distributed beamforming with two distributed transmitters, both transmitting to one receiver.
The proposed design for the distributed beamforming have a two antennas at the transmitter side. For Phase calibration, we have to divide the reference signal into two parts. Each transmitter will have one part of signal and all the other parts of signal will be zero. The signal at TxA of node 1 will be the first half of reference signal followed by zeroes in the other halves. The signal at TxA of node 2 will have zeros in the first half followed by reference signal in the second half. At the end there will be a summation of all these two signals at the receiver, so we can determine the phase difference between each transmitting node and it can be corrected in MATLAB manually to get proper signal at receiver side.

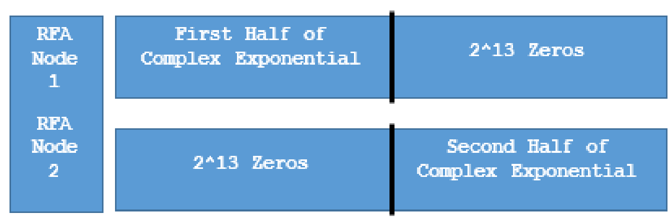

Figure 5Phase Calibration Signal [11]

The proposed design for this case is implemented using two transmitters, each consisting of one antenna at each node and a receiver with one antenna. These two transmitters will be placed in large area and will be at that fixed location for the entire experiment. The measuring node (Rm) will measure the amplitude and RSSI value for transmitted message signals at different locations on the grid. The size if the grid is 5×5.

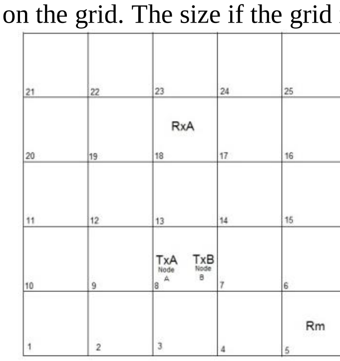

Figure 4 Proposed Experimental Setup Third Case

Expected Results:

Case 1: Here, as the transmitter is omnidirectional the reference node (Rm) will have high amplitude and RSSI of the transmitted message signal throughout the grid.

Case 2: Here, the transmitters are unidirectional and therefore the reference node (Rm) will have higher amplitude and RSSI values of transmitted message signal in the central part of the grid as compared to the boundary of the grid.

Case 3: Here, as the transmitting antennas are from two different WARP boards, they will produce distributed beamforming resulting in a very strong unidirectional signal in the direction of intended receiver. Therefore, the reference node (Rm) will measure high amplitude and RSSI values of the transmitted message signal only between the path of the transmitter and the intended receiver.

IV. REQUIRED RESOURCES

Table 1 Required Recourses

	Case 1	Case 2	Case 3
WARP board	3	3	4
Antenna	3	4	4
LAN cables	4	4	5
Ethernet Switch	1	1	1
RF cables	0	0	2
Twisted pair cable	0	0	2
Laptop	1	1	1
Power Cables	3	3	4

For Part one, one WARP board will be acting as a transmitter, one as a receiver and one to measure the RSSI value or for spectrum sensing. The transmitter and the receiver will be connected to Ethernet switch and the switch will be connected to the laptop. For the second part, one WARP board with two antennas as transmitter, one WARP board with one antenna acting as a receiver and one WARP board with one antenna to measure RSSI. Transmitter and receiver will be connected to ethernet switch and the switch will be connected to the laptop.

For Third part, two WARP boards with one antennas each, will be acting as transmitter and one WARP board with one antenna acting as a receiver and another WARP board with one antenna to measure RSSI. The two transmitters and the receiver will be connected to Ethernet switch and the switch will be connected to the laptop. RF cables are used to synchronize clock between two transmitting nodes.

V. RESULTS

For all the three cases, we have divided the experimental area into a grid of rows and columns having five rows and five columns. Each grid is numbered in increasing order Fig.2. The measurement receiver will measure the amplitude and the RSSI of the transmitted message signal throughout the grid.

Case 1[without beamforming]:

In this part, two antennas have been used, one at the transmitter node (Tx) and the other at the receiver node (Rx) as described in case (1).

In the figures below, the RSSI value in each area of the grid is the representation of the RSSI value of the reference receiver. The measurements for the amplitude is taking in the same way and has the same explanation.

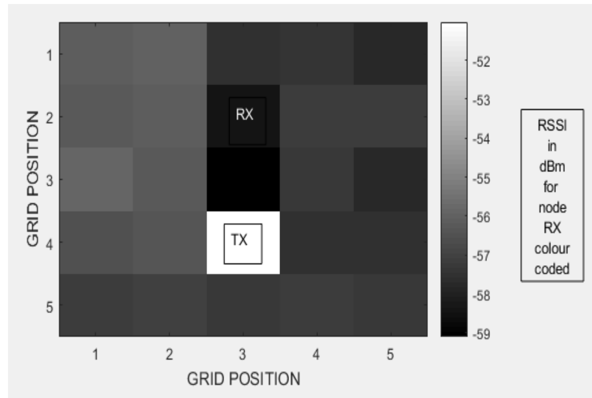

Figure 6 Case 1 RSSI for Receiver

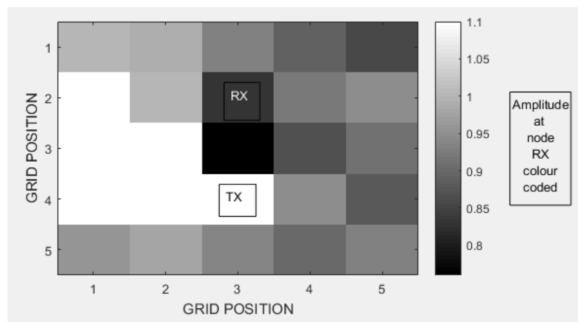

Figure 7 Case 1 Amplitude for Receiver

In the figures below, the RSSI value in each areas of the grid is the representation of the RSSI value of that particular area where the grid has been measured. The measurements for the amplitude is taking in the same way and has the same explanation.

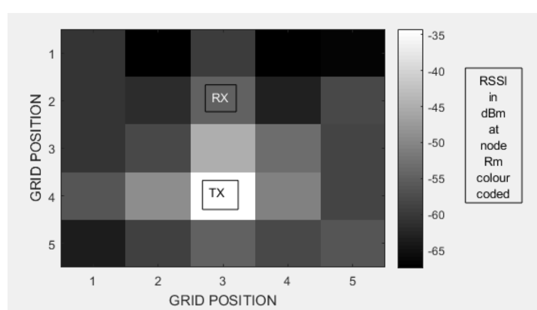

Figure 8 Case 1 RSSI for Reference Measurement node

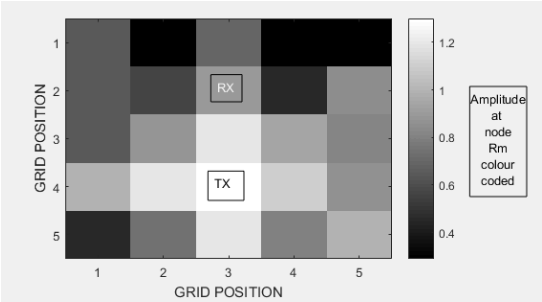

Figure 9 Case 1 Amplitude for Reference Measurement node

Case 2[with beamforming]:

In figures below, the RSSI value at any particular area of the grid represents the RSSI value of the reference receiver. The value of the power at the receiver end doesn't change gradually or exponentially when the measured at different locations in the grid except when measured near the transmitter. The measurements for the amplitude is taking in the same way and has the same explanation.

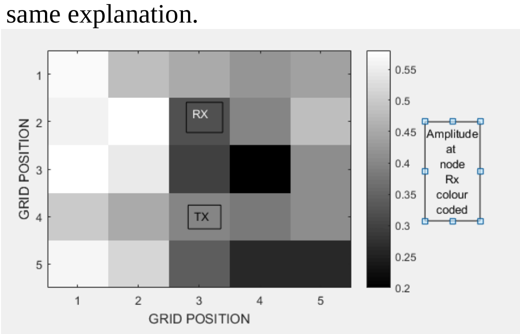

Figure 10 Case 2 Amplitude for Receiver

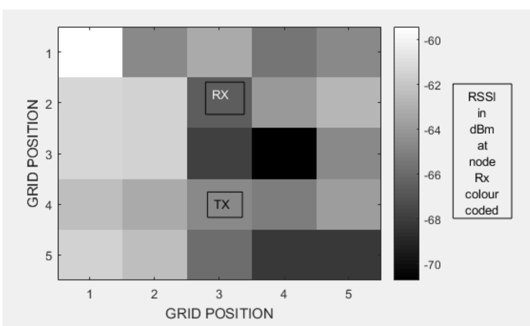

Figure 11Case 2 RSSI for Receiver

In figures below, the RSSI value at any particular area in the grid represents the RSSI value of the receiver placed in that particular area. Also, the lighter gray area is the part where RSSI is higher and the darker gray area is the part where the RSSI is comparatively lower. When these values are plotted using heat map as shown below, a beamforming takes place in one particular direction. The measurements for the amplitude is taking in the same way and has the same explanation.

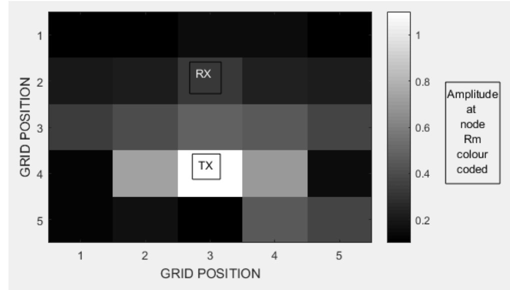

Figure 12 Case 2 Amplitude for Reference Measurement node

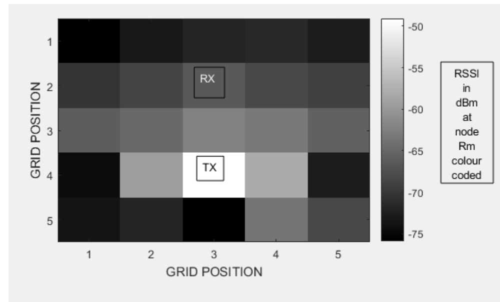

Figure 13 Case 2 RSSI for Reference Measurement node

Case 3[with Distributed beamforming]:

The difference between the case 2 and case 3 is that in case 3, two antennas have been used at the transmitter end each on two different nodes and one at the receiver node.

In figures below, the RSSI value in each area of the grid is has reorientation if the RSSI value of the reference receiver. The value of the power at the receiver end doesn't change gradually or exponentially when the measured at different locations in the grid except when measured near the transmitter. The only difference between figure 11 and figure 15 is that the gain is lower for this entire part than compared to case 2. The measurements for the amplitude is taking in the same way and has the same explanation.

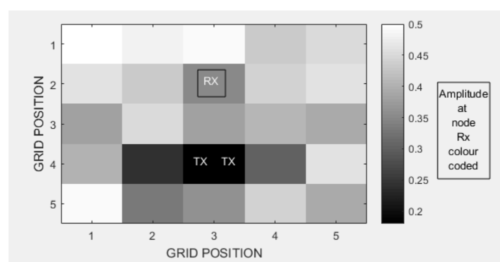

Figure 14 Case 3 Amplitude for Receiver

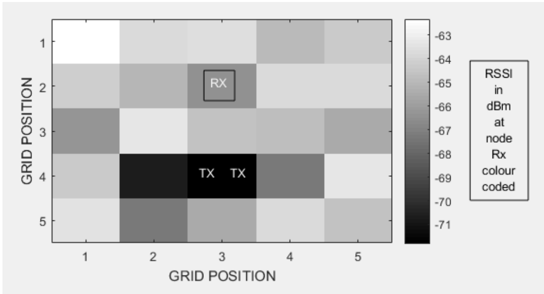

Figure 15 Case 3 RSSI for Receiver

In figures below the RSSI value in each area of the grid is the representation of the RSSI value of that particular area where the grid has been measured. The areas like 4x2, 4x3, 4x4 and 3x3 has higher power than the other areas of the grid. When these values are plotted using heat map as shown below, a beamforming takes place in one particular direction. The main difference between figure 13 and figure 17 is that the gain is lower in figure 13 than figure 17. Also, the RSSI values are lower in figure 17 than compared to figure 13. The measurements for the amplitude is taking in the same way and has the same explanation.

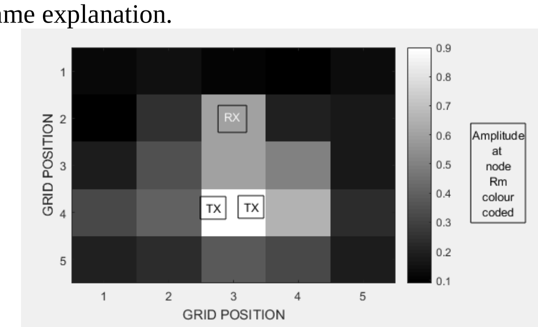

Figure 16 Case 3 Amplitude for Reference Measurement node

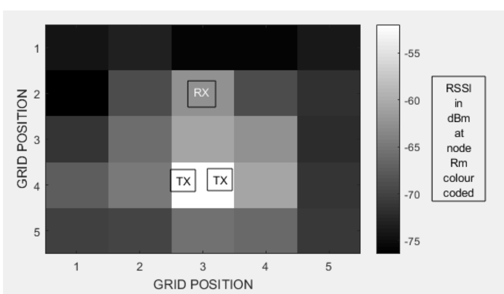

Figure 17Case 3 RSSI for Reference Measurement node

VI. Future Scope

Clock Drift:

To measure the clock drift between two beamforming nodes where each transmitter is transmitting the same signal. Since, both these transmitters will not share the same CPU, they will not have clock synchronization and there is a possibility that both these transmitters start their transmission at different times resulting in an out of phase signal at the receiver. One way to find the clock drift is that, we transmit signal from both transmitters which has their first halves as complex exponential or sinusoidal signal and second halves zeros. So, if there is any clock drift between two signals at receiver, from received constructive signal, we can possibly see some part of first half of the signal in the second part of the signal at receiver. Ideally, if there is no clock drift there can be some phase difference in first half of received signal but in the second half of the received signal, there will be will be zeros.

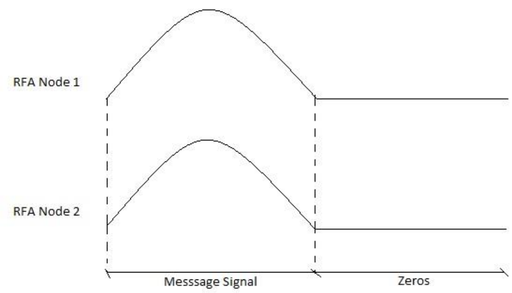

Figure 18 Signals To measure clock drift

Also, we can improve the efficiency further by increasing number of nodes at the transmitter side. Also, introducing feedback system eg. 1-bit feedback system can improve the phase synchronization and time synchronization.

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