Analysis of TDMA based MAC protocols with Cooperative diversity

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Abstract- **MAC protocol is usually contention based or reservation based. Whereas contention based protocols are easily implementable, they consumes a lot of energy and have a higher ratio of delay time and lesser throughput. On the other hand reservation based protocols like TDMA and CDMA do not need to contend the channel beforehand because all users get their turns for channel usage. Hence, while contention based protocols waste energy, reservation based protocols are energy efficient and help in increasing battery life of the devices. Furthermore, cooperative diversity is used along with MAC protocols to lessen fading. In this regard C-TDMA [1] is a very popular protocol. But the authors form a very redundant channel. This paper tries to nullify the paper's claim; to form a good cooperative diversity MAC protocol, many number of helper (relay) nodes need to be used. The paper further proves that only a single relay node is necessary for forming a good cooperative MAC protocol. Results will prove that throughput increases and BER is also neutralized. MRC is used to deal with the direct and indirect signals in the system at the receiver. Amplify and forward has been used as the cooperative diversity technique since it is the simplest and easiest one. Overall this paper concentrates on the benefits and disadvantages of both the types very concisely and incites further research ideas.**

Keywords-Cooperative diversity, relay, BER, network throughput, relay selection, TDMA

I. Introduction

The wireless architecture is divided into 7 layers where each plays a role in the transmission and reception of data via a communication channel. MAC layer is assigned the role of integrating a large number of users and synchronizing the channel accordingly [8]. The nature of MAC layer covers areas like energy usage, collision detection and/or avoidance etc.

TDMA is a MAC layer reservation-based protocol; less popular but highly energy efficient, which is a beneficial quality to have. Since MAC layer performs the task of providing channel access to individual users therefore it is necessary that collisions be avoided, which again proves that TDMA is a very useful technique.

Cooperative diversity was introduced as a possibly better diversity technique for 4G and 5G [2]. For a long time, there has been research on implementing it with MAC layer protocols. In [15], cooperative diversity was implemented with slotted aloha which is a contention based MAC protocol. As its name suggests, each user/node needs to first contend the channel based on its availability. Implementation of cooperative diversity is difficult and takes a lot of time.

On the other hand, C-TDMA transmits the data signal send from a source, $N+1$ times. This way a MISO cooperative system is formed with a diversity gain of $N+1$. Each node transmits in its own time slot and forwards the same data packet. Since each node/user has equal access to the channel on the basis of time division of the channel frame, therefore the time needed to contend the channel is saved. In this manner the implementation of cooperative diversity becomes easier and more energy efficient.

Logically it can be concluded that modern wireless technology needs to be designed in a way that a large number of users can access the channel together or in a very small time difference from each other [4]. Although TDMA helps in regard, but in case of C-TDMA no methodology for lessening overhead created by transmission of $N+1$ numbers of data packets for cooperative diversity is proposed.

It can also be said that in case of transmission failure via source to destination, when all the other nodes will transmit data cooperatively, then the destination will have to wait for a further N time slots for a single data packet. This is energy wastage. Based on the protocol of C-TDMA, this paper proposes a TDMA based MAC protocol where only one relay node transmits failed data packets as opposed to transmission from N relay nodes. It is named 1 node C-TDMA as opposed to N node C-

TDMA. The results of both are compared and analyzed on the basis of BER, SNR, delay and throughput.

In our paper a frequency selective Rayleigh Fading channel and Amplify and forward technique for both methods of TDMA cooperative diversity have been used.

The rest of the paper is laid out as follows: section 2 concentrates on a detailed analysis of C-TDMA MAC protocol with N number of relays and C-TDMA with 1 relay; section 3 explains systems preliminaries for the systems. Section 4 is an analysis of the outcomes of the methodologies studied with the conclusion given in section 5.

II. What is TDMA based cooperative MAC Protocol

TDMA does not have to listen to the channel for contention all the time, thus saving energy [10]. The users on the channel are each allotted a specific time slot and they only transmit in that slot. Therefore, the needs to constantly listen to the channel for an empty slot and collision during transmission are completely obliterated.

TDMA is a very well suited environment for cooperative diversity. As Fig. 1 shows, diversity means relay nodes are used for forwarding the transmission signal to the destination via an indirect link as well as the direct link [9]. The direct link is denoted by $H_{S,D}$ whereas $H_{S,R}$ and $H_{R,D}$ both depict the indirect link. S, D and r represent source, destination and relay node respectively. TDMA is mainly used to synchronize this diversity in cooperation; relay node acquires the data signal via broadcast from source nodes and relay that data in their own time slots. Here the source transmits first and that is the direct transmission. The other node (relay) transmits after the source and that becomes the indirect transmission.

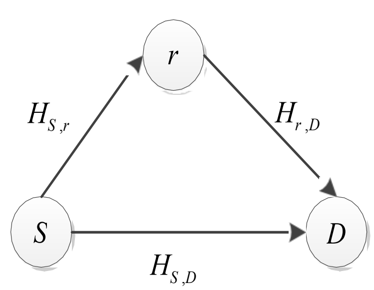

Figure II-: Layout of Cooperative Diversity

In most recent papers, cooperative diversity and relays have been reduced to a single channel [12], [13], [14]. This destroys the main essence of cooperative diversity since this method was devised to lessen channel fading by using the other reflected signals to fortify the main transmitted signal from source to destination. If relay nodes are only used as a back-up, then the diversity gain at destination remains 1 and the probability of channel fading is hardly lessened. Therefore this paper concentrates on a diversity gain of 2 in single node C-TDMA and gain of $N+1$ in N nodes C-TDMA where N represents the total number of relay nodes.

A diversity gain of 2 is maintained by sending a signal via the direct link and one via the indirect link. The relay used is assumed to be the optimal one and is available for cooperation.

When both the data packets are receives at the destination, it checks for errors and send an ACK back if the packets are received correctly. Maximal Ratio Combining is used for combining the multiple data packets at the destination terminal.

With cooperative diversity it is necessary that the a few changes be made while using TDMA MAC protocol since in conventional transmission there is only one link transmission. The major points to keep in mind are that since relay nodes cooperate in eradicating the channel fading, therefore the MAC system needs to adjust these relays as well. A possible solution is that the relay nodes be assigned time slots for transmission after all the sources have transmitted [11]. But this way the destination will have to wait a long time for the data packets that a delivered via the relay nodes. This increases delay a lot. Therefore it only wastes energy. Another way is to use the relay node only as a backup when the transmission via direct link fails [12]. Therefore it is a tradeoff between the two. Given the requirements for the system one can be given priority over the other.

III. Proposed TDMA based Cooperative MAC Protocol

A. N node C-TDMA:

In C-TDMA protocol there are N numbers of relay nodes, and all of them are used for cooperatively forwarding the same data packet. When the source is transmitting (broadcasting) a signal, all of the other relay nodes are hearing and save the data packet. At their own turn to transmit, they send the same data packet to the destination instead of transmitting a different data packet. In this way the destination has a total of $N+1$ data packets. All of these signals are combined together via a combination technique, like MRC to achieve the optimum data packet. The SNR of this data packet is the average of all of the signals. The created network with diversity looks like Fig. 2.

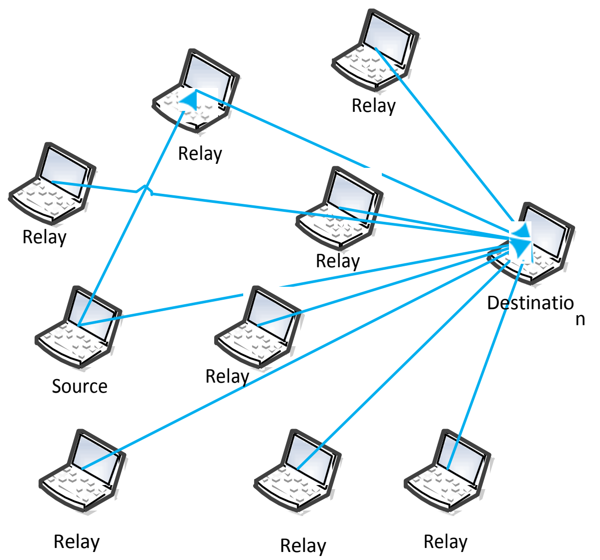

Figure III-: Layout of cooperative diversity for N node C-TDMA

B. Single node C-TDMA

In this protocol, a single relay node is used to transmit the data signal apart from the source node itself. The flow of the protocol is as such: the source node broadcasts the data packet it wants to transmit to the destination. It is heard by all the remaining relay nodes. The next node with its turn for transmission transmits the data packet and waits for an ACK. If the destination receives both of the signals, then it sends an ACK back. Otherwise, the relay after this one transmits the same data packet to the destination and awaits ACK. This way, it is ensured that the destination has two data packets before sending an ACK back.

The protocol is illustrated in Fig. 3. It is ensured that the diversity gain remains more than 1 so that the essence of cooperation is preserved. The channel is Rayleigh multipath fading. At the destination, once again MRC is used to combine both the signals.

IV. System analysis

The channel used is Rayleigh Multipath Fading. The transmit signal is given by (1), where $x_b(t)$ is the baseband signal, f_c is the carrier frequency and t is the time, with the n^{th} path attenuation is $a_n(t)$ and $\tau_n(t)$ is the delay. Therefore we get the received signal in (2) which is further modified in (3), (4) to get the resultant signal in (5).

$$x(t) = R\{x_b(t)e^{j2\pi f_c t}\} \quad (1)$$

$$r(t) = \sum_n a_n(t)x[t-\tau_n(t)] \quad (2)$$

$$r(t) = R\left\{\sum_n a_n(t)x_b[t-\tau_n(t)]e^{j2\pi f_c[t-\tau_n(t)]}\right\} \quad (3)$$

$$r^b(t) = \sum_n a^n(t)e^{-j2\pi f_c \tau_n(t)} x^b[t-\tau^n(t)] \quad (4)$$

$$r_b(t) = \sum_n a_n(t)e^{-j\theta_n(t)}x_b[t-\tau_n(t)] \quad (5)$$

Where $\theta_n(t) = 2\pi f_c \tau_n(t)$ is the phase of the n^{th} path and the impulse response is $h_b(t) = \sum_n a_n(t)e^{-j\theta_n(t)}$.

For N node C-TDMA, n is equal to the total number of nodes present in the network, minus the destination node whereas for single node C-TDMA, n is equal to 2.

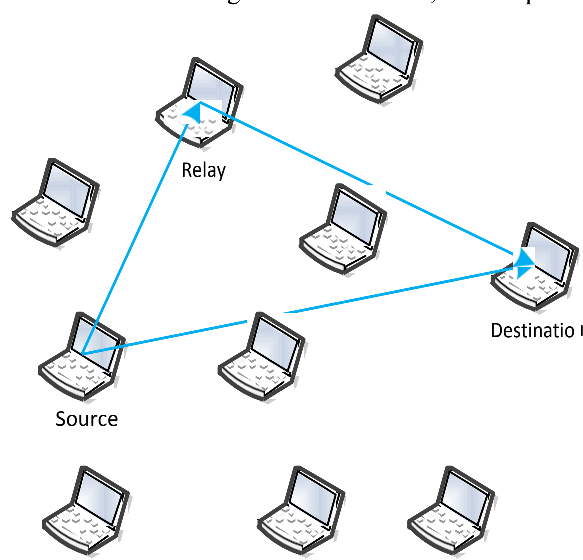

Figure IV-: Layout of cooperative diversity for single node C-TDMA

In Fig. 4, we show BER versus SNR for single and N node C-TDMA in a Rayleigh Fading channel. The graph suggests that single node C-TDMA yields a better BER as compared to N node C-TDMA. This is because of the negative impact of relays which do not add positively to the cooperative diversity: viz. the nodes which lay farther away from destination than the source itself. Therefore the possibility of a bad signal distorting the good signals while being combined together has to be kept in mind. This proves that instead of bombarding the destination with a lot of signals, it is better to send only two good quality signals.

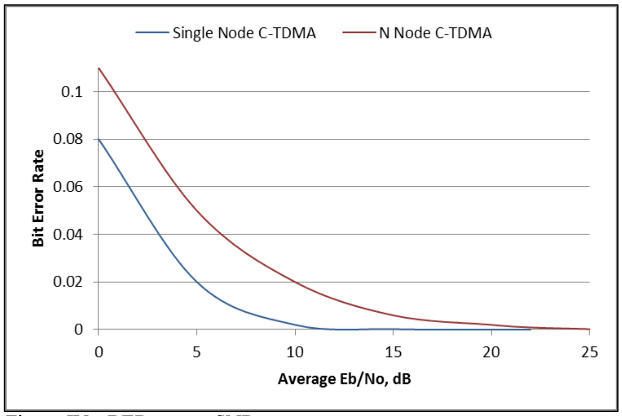

Figure IV-: BER versus SNR

Throughput versus distance achieved for the single node and N node C-TDMA and is shown in Fig. 5. Here the distance is between source and destination nodes. The graph clearly represents that throughput with single node C-TDMA is better than N node C-TDMA. But it should be noticed that this outcome is true only for small distances. As the distance increases the throughput for single node C-TDMA falls rapidly and at distances above 70m, they completely disappear, whereas the throughput for N node C-TDMA persists for at least distance of 90m. The reason for this discrepancy is that as distance between source and destination increases, there is less probability of presence of a relay node to forward the data to destination without fading or interference. On the other hand, as distance between source and destination increases, there is still the probability of finding nodes which send a signal to the destination without fading and interference. Therefore, for short distances, single node C-TDMA yields great results.

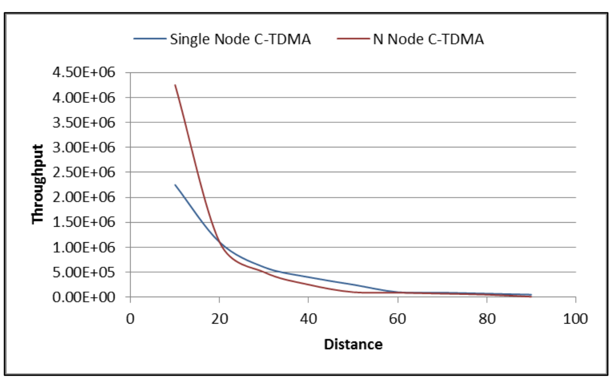

Figure IV-: Throughput versus distance

The Fig. 6 shows the delay versus distance where delay is measured by the reception of ACK from the destination. Here again the distance is between source and destination. It is logically obvious that the delay for N node C-TDMA is more than single node C-TDMA. This is because the destination receives an entire data packet in a single channel frame instead of a small time slot. This way the destination sends an ACK after that channel frame. Contrarily, the single node C-TDMA uses only two time slots to forward a data packet to the destination. This yields a lesser delay because destination gets both the data packets and is ready to send ACK sooner than in N node C-TDMA. Hence this also proves that single node C-TDMA is a better protocol than N node C-TDMA.

The main aim of modern wireless networks is to allow a lot of number of users for access the channel together. If a single data packet takes an entire channel frame for transmission then this aim is clearly not fulfilled. The result for a single user transmission is good, but will deteriorate slightly with the presence of more users, causing an increase in delay and BER and decrease in throughout.

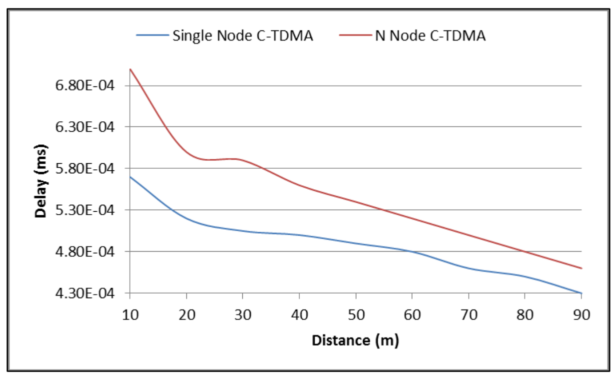

Figure IV-: Delay versus distance

V. Conclusion

While working in a MAC layer, several conditions need to be considered, including the number of users, the acknowledgement received after successful reception of data frames, the length of the data to be transmitted, selection of the right path (direct or indirect) for data transmission, and delay during transmission etc. [3]. Transmission failure also wastes energy, therefore finding a diversity system which decreases the Bit Error Rate is a very optimum way to go [5]. Also the very important factor of choosing a relay which allows a good cooperative link should be a good path for research [6], [7].

The aim of this paper was not to concentrate on questions regarding, who to cooperate with, the optimal relay, how these relays cooperate with each other or how they are selected. Instead this paper assumes that a relay(s) is present with the source, is willing to cooperate and is optimal. Thus this paper concentrates on comparing the use of one relay against many. In short it targets simulations regarding outcomes for the two types of C-TDMA based MAC protocol for cooperative diversity on the basis of distance between source and destination. Also it finds simulation results for BER and SNR on by keeping these distances as a base. The paper also aims at proving the worth of TDMA schemes in cooperative environments as other MAC protocols. It is seen that as long as the number of users are less, and no interference is suspected, TDMA can prove to be a very efficient system as it has less delay due to queuing, more power efficiency and more network throughput. References [16], [17] argue that the channel is improved when diversity is applied. Therefore this fact mixed with new and innovative multiple access schemes, the wireless technology can be improved a lot.

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