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An Improved Scheme for Collision Resolution in Cooperative Communication

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ABSTRACT

This paper presents a new approach to resolve collision on the collision resolution areas of the data networks. Cooperative communication is one of the newest techniques to form virtual antennas. In order to address the increased traffic to meet the demand of future wireless applications proper allocation of the spectrum has always been a needful task. The conventional cooperative communication makes efficient allocation of the spectrum by transmitting data on all the subchannels. Here, we developed an improved cooperative scheme by taking the benefit of shared subchannel irrespective of the adjacent slots to reduce the time that a packet spends on the subchannel. This improved scheme i.e. Scheme C claims to reduce the average processing time for a consecutive increase in the subchannel. Besides the proposed scheme for resolving collisions is experimentally considered and compared to show that it withstand bandwidth efficiency.

Key words: Cooperative Communication, Collision Resolution, Shared Subchannel, Increased Traffic, Scheme C

INTRODUCTION

Wireless communication is not only one of the most vibrant research areas in the communication field, but it is also one of the biggest engineering successes of the last twenty years. Cooperation and cross-layer design are two emerging techniques for improving the performance of wireless networks. It is well known that multiple-input multiple-output (MIMO) systems can significantly improve the performance of data networks, e.g., increase data rate, reduce interference, and improve link reliability. However, due to the cost, size or hardware limitations, multiple antennas are not available at network nodes in many scenarios. For such scenarios, user cooperation can create a virtual MIMO system and thus enable a single-antenna user to enjoy the benefits of MIMO systems.

Transmissions via cooperation can be typically modeled as a traditional relay channel. In a simple relay channel model, there are one source, one destination and one relay in the network. The source first transmits its message to the destination; the relay overhears the message due to the broadcast nature of the wireless channel. Then, the relay forwards the message to the destination in either a "decode-and-forward" or, an "amplify-and-forward" fashion.

Traditionally, protocol design in wired and wireless networks was primarily based on layered approaches that facilitated standardization and implementation. For example, the physical layer is responsible for the reliable and efficient delivery of information bits, while the medium access control layer is responsible for resource management among multiple users in the network. In layered protocols, each secluded layer in the protocol stack is considered and operated independently, with predefined interfaces linking layers that are stationary and independent of system constraints and applications.

RELATED TASK

Future wireless networks are complex extensions of cellular networks. They will need to accommodate multimedia services such as video, teleconferencing, internet access, and voice communications. Multimedia sources have diverse bandwidth requirements and are bursty in nature, thus fixed bandwidth allocation schemes are inefficient for them. Simple medium access schemes for bursty sources include random access methods. An example of such system is the slotted ALOHA [5], which allow users to transmit in an uncoordinated fashion every time they have a packet to transmit.

Collision resolution has been investigated from both the MAC and physical layer perspectives. According to [7], in a K-fold collision, the packets involved in the collision are not discarded but rather stored in memory and later combined with retransmissions initiated during the slots following the collision slot. Moreover, to avoid extra control overhead, the NDMA scheme requires that all collided users retransmit in each of the time slots following the collision, which may drain the battery power of users involved in high order collisions.

Recently a new cooperative media access control protocol of random access wireless network was proposed in [5]. Due to that scheme, when there is a collision, the destination node (base station) does not discard the collided packets but rather saves them in a buffer. In the slots following the collision, a set of nodes designated as relays, form an alliance and forward the signal that they received during the collision slot. Based on these transmissions, the base station formulates a multiple-input multiple-output problem, the solution of which yields the collided packets. The method of [5], referred to here as ALLIANCES, maintains the benefits of ALOHA systems in the sense that all nodes share access to media resources efficiently and with minimal scheduling overhead, and enables efficient use of network power.

The cooperative medium access protocol scheme described in the context of cellular networks or wireless LAN, where a set of nodes, denoted by, $\mathcal{R} = \{1, 2\ldots J\}$ communicates with the Access Point. Thus all the transmission initiated by a source node $i \in \mathcal{R}$ are directed to a single destination $d \notin \mathcal{R}$ which is the base station or the access point.

Consider a small-scale slotted multi-access system with J users, where each node can hear from a base station or access point on a control channel. Link delay and online processing (packet decoding) time are ignored and all transmitters are assumed synchronized. Each user operates in a half-duplex mode. Every user and the BS/AP are equipped with only one antenna. All transmitted packets have the same length and each packet requires one time unit/slot for transmission.

Let us consider a network with J nodes. Suppose that K packets have collided in the n-th slot. All nodes not involved in the collision enter a waiting mode and remain there until the collision is resolved. The collision resolution period is defined as a cooperative transmission epoch (CTE), beginning with the n-th slot. The AP will send a control bit to all nodes indicating the beginning of CTE and will continue sending this bit until the CTE is over.

Let the packet transmitted by the i-th node in slot n consist of N symbols, i.e.

$$x_i(n) \triangleq \left[x_{i,0}(n), \ldots\ldots, x_{i,N-1}(n)\right] \qquad (1)$$

Let $S(n) = \{i_1, \ldots\ldots, i_k\}$ be the set of sources and $\mathcal{R}(n) = \{r_1, \ldots\ldots, r_{\hat{k}-1}\}$ be the set of nodes that will serve as relays, and 'd' denotes the destination node. During the n-th slot, the signal heard by the AP and also the source node is:

$$y_r(n) = \sum_{i \in S(n)} a_{ir}(n) x_i(n) + w_r(n) \qquad (2)$$

where, $r \in d \cup \mathcal{R}(n), r \notin S(n), a_{ir}(n)$ denotes the channel coefficient between the i-th node and the receiving node r; and $w_r(n)$ represents the noise.

Once the collision is detected, the AP sends a control bit, for example '1' to all the nodes indicating the beginning of a cooperative transmission epoch (CTE). The CTE consists of $\hat{k} - 1$ slots with $\hat{k} \geq K$. The BS keeps sending the same control bit in the beginning of each CTE slot. During slot, $n + 1,\ 1 \leq K \leq \hat{k} - 1$ one node is selected as a relay. The selection is based on the predetermined order, for example, each node computes the $r = \mathrm{mod}\ (n + k, J) + 1$ and the node which ID equals to 'r' knows that it has to serve as a relay.

Due to the half duplex assumption, if the chosen node happened to be a source node during the collision slot, it will simply retransmit its own packet. Thus, only one relay is active during each of the slots of the CTE. Nodes that are neither involved in the collision nor act as relays remain silent until the CTE is over. When the CTE is over the BS sends a '0' to all nodes, informing them of the end of the CTE.

The received signal at the BS is:

$$z_d(n + K) = \begin{cases} a_{rd}(n + k) x_r(n) + w_d(n + k), \\ \qquad r \in \mathcal{R}(n) \cap S(n) \\ a_{ir}(n + k) c(n + k) y_r(n) + w_d(n + k), \\ \qquad r \in \mathcal{R}(n), r \notin S(n) \end{cases} \qquad (3)$$

where,

$z_d(n + k)$ is a $1 \times N$ vector

$w_d(n + k)$ denotes the noise vector at the access point

$c(n + k)$ is the scaling constant

Let us define matrices X, whose rows are the signals sent by source nodes i.e. $x_{i_1}(n),, \ldots\ldots, x_{i_k}(n)$ and Z, whose rows are the signals heard by the destination node during slots $n,\ n + 1, \ldots\ldots,\ n + \hat{k} - 1$ i.e. $z_d(n),\ z_d(n + 1)$, $z_d\left(n + \hat{k} - 1\right)$ with $z_d(n) = y_d(n)$. Without loss of generality, let us further assume that among the $\hat{k} - 1$ nodes, the first l nodes are non-source relays nodes, while the next η nodes are the source relays, where $l + \eta + 1 = \hat{k}$

The received signal at the destination can be written in matrix form as:

$$\mathbf{Z} = \mathbf{H}\,\mathbf{X} + \mathbf{W} \qquad (4)$$

where, the matrix **H** and **W** contains channel coefficients and noise respectively. Once, if the **H** i.e. the $\hat{k} \times K$ matrix is estimated, the transmitted packet can be obtained via maximum likelihood decoder.

The channel estimation and active user detection is done through the orthogonal ID sequences, s_i (i is the user index) that are attached to each packet as in [7]. The ID sequences are also used as pilots for channel estimation. At the BS, the correlation of the received signal and the ID sequences s_i, is performed.
Due to the orthogonality of the s_i , it holds:

$$z_s(n)\, s_i^H = \begin{cases} 0 & \text{user i is absent} \\ 1 & \text{user i is present} \end{cases} \quad (5)$$

The collision order K, can be detected by comparing $|u_i(n)|$ to a pre-defined threshold. The CTE extends over $\hat{k}-1$ slots with $\hat{k} \times K$. If the channel conditions between relay and destination during a certain CTE slot is so bad that it impossible for the BS to collect information, the BS will increase by one. The BS will continue updating until enough information was gathered for resolving the packets.
After detection of the collided user set $i_1, \ldots\ldots, i_k$, the channel matrix H can be obtained based on $u_{i_k}(n+m)$ with $0 \le m \le \hat{k}-1$. Once the receiver collects independent mixtures of the original transmitted packets, the collision can be resolved via a maximum likelihood (ML) or a linear equalizer (e.g. zero-forming (ZF) and minimum mean square error (MMSE) equalizer.

METHODOLOGY

In this section, Multichannel Cooperative MAC protocol - a multichannel extension of cooperative MAC protocol that further improves throughput in case of high traffic load is explained and studied. The cooperative protocol assumed a flat fading channel. However, in reality the channel is usually frequency selective. Although frequency selective fading is difficult to deal with, if compensated for successfully, it can be viewed as a source of multipath/frequency diversity.
Consider a similar scenario as in [5], except that the channel has L taps. The physical layer is based on orthogonal frequency division multiplexing (OFDM) system with F carriers. The carriers are grouped into groups of F/M to form M subchannels $C_m, = 0, \ldots\ldots, M-1$ .Without loss of generality, assume that F/M is an integer. Also, we assume that the subchannels are non-interfering with each other.
A user cannot hear and transmit on the same subchannel at the same time. Each packet has a fixed length, contains b bits, and occupies one subchannel for its transmission. If B blocks of OFDM symbols, say QPSK symbols, are transmitted in one slot, then each packet contains b = 2BF/M bits.

Transmission on all subchannels

Each user transmits on all subchannels simultaneously. Therefore, if a collision occurs, the collision order is the same on all subchannels. Let us term the process of resolving packets that collided over C_m as CTE_m. Two different schemes for resolving collisions will be considered and compared.

Scheme A - Collisions on each subchannel are resolved independently

A collision on subchannel C_m is resolved by involving C_m only. For a K-fold collision on C_m, the subchannel C_m will be reserved for the next $K-1$ slot, and the collision will be resolved along the lines of [5]. For simplicity, we take $\hat{k} = K$. From the MAC layer point of view, K slots are needed to resolve the M collisions of order K, and thus the delay is exactly the same as in ALLIANCES and NDMA. Therefore, the analysis of [7] applies in this case.

Scheme B - Subchannels are used in a shared fashion to resolve collision on a particular subchannel

In this scheme, advantage of the available subchannels is taken to reduce the average processing time, i.e., the time that a packet spends on the channel. Let the collision order on each subchannel in slot n be K. During CTE_m, a set of nodes designated as relays use a set of subchannels indicated to them by the BS to retransmit what they heard during the collision slot on C_m. If the relay node is a source node that transmitted over C_m, it will not retransmit its original packet to the subchannel as indicated by the base station rather it will retransmit to the another subchannel. Following a collision slot, the BS will first allocate all available and necessary subchannels for CTE_0, then allocate subchannels for CTE_1, until CTE_{M-1}. Let T_m denote the processing time on the channel (in slots) for each packet that collided on C_m or equivalently, the duration of CTE_m plus one.
The average processing time is:

$$T_m = \frac{1}{M}\sum_{m=0}^{M-1} \tau \quad (6)$$

Scheme C – Shared Subchannel are used to resolve collision irrespective of the adjacent slot to resolve collision on a particular subchannel

Case I:

In this scheme also we take the advantage of the available subchannels to reduce the average processing time i.e., the time that a packet spends on the channel.

Table -1 Subchannel Allocation for Scheme C

Subchannel/Slot	n + 1	n + 2
C_0	CTE_0	CTE_1
C_1	CTE_0	CTE_1

Let us consider a system with only two subchannels. In slot n, three packets collide over each of C_0 and C_1 respectively. The subchannel allocation of the multichannel scheme is shown in Table 3.1. In the (n + 1)th slot, the BS allocates both subchannels for CTE_0, i.e., to resolve the collision that occurred over C_0, and in slot n + 2, it allocates two subchannels for CTE_1, i.e., to resolve collisions that occurred over C_1. At the end of the (n + 1)th slot, we consider the collision that occurred over C_0 has not been resolved. The collision that occurred over C_1 is resolved at the end of (n + 2)th slot. So the processing time for packets over C_0 is 3 slots, while the processing time for packets over C_1 is 2 slots. Therefore, the average processing time is (3 × 3 + 3 × 2)/6 = 2.5 slots. Note that the average processing time of Scheme A is 3 slots.

Case II:
Let us consider a system with only three subchannels. In slot n, four packets collide over each of C_0 and C_1 respectively. The subchannel allocation of the multichannel scheme is shown in Table 3.2. In the (n + 1)th slot, the BS allocates both subchannels for CTE_0, i.e., to resolve the collision that occurred over C_0, and in slot n + 2, it allocates two subchannels for CTE_1, i.e., to resolve collisions that occurred over C_1. At the end of the (n + 1)th slot, we consider the collision that occurred over C_0 has not been resolved. The collision that occurred over C_1 is resolved at the end of (n + 2)th slot. So the processing time for packets over C_0 is 4 slots, while the processing time for packets over C_1 is 3 slots. Therefore, the average processing time is (4 × 4 + 4 × 3 + 4 × 4) / 12 = 3.66 slots.

Case III:
Let us consider a system with only four subchannels. In slot n, five packets collide over each of C_0 and C_1 respectively. The subchannel allocation of the multichannel scheme is shown in Table 3.1. In the (n + 1)th slot, the BS allocates both subchannels for CTE_0, i.e., to resolve the collision that occurred over C_0, and in slot n + 2, it allocates two subchannels for CTE_1, i.e., to resolve collisions that occurred over C_1. At the end of the (n + 1)th slot, we consider the collision that occurred over C_0 has not been resolved. The collision that occurred over C_1 is resolved at the end of (n + 2)th slot. So the processing time for packets over C_0 is 5 slots, while the processing time for packets over C_1 is 4 slots. Therefore, the average processing time is (5 × 5 + 5 × 4 + 5 × 5 + 5 × 5)/20 = 4.75 slots.

Mathematical Formulation
Let us consider that the physical layer is an F-carrier OFDM system, where the carriers are divided into groups of N carriers each, i.e., $C_0, \dots\dots, C_{M-1}$ with N = F/M.
Let $h_{ij}(m;n); m = 0, \dots\dots, L-1$ denote the L channel taps between nodes i and j during slot n. We will assume that L is the length of the longest among all internodes channels.
The F-point discrete Fourier Transform (DFT) of $h_{ij}(m;n)$ is:

$$H_{ij}(k;n) = \sum_{m=0}^{L-1} h_{ij}(m; ne^{-j\frac{2\pi k_m}{F}})$$
$$k = 0, \dots\dots, F-1 \quad (7)$$

OFDM with sufficiently long Cyclic Prefix (CP) can convert a frequency selective channel into multiple flat fading channels. The effect of the channel over the k-th carrier is just a multiplication by the carrier gain, $H_{ij}(k;n)$
A packet consists of B OFDM symbols. Let $x_i^m(n)$ is a B × N matrix denoting the packet sent by user i over subchannel m, in slot n. Each row of that matrix contains an OFDM symbol before modulation. In the absence of collision and after demodulation, the received packet at the BS equals:

$$\boldsymbol{y}_d^m(n) = \boldsymbol{x}_i^m(n) + \boldsymbol{w}_d^m(n) \quad (8)$$

$\boldsymbol{H}_{id}^m(n) = [\boldsymbol{H}_{id}(mN;n), \dots\dots, H_{id}(m+1)N-1;n]$ (N × N) B × N matrix denoting noise at the BS over C_m. Now, suppose that a collision of order C_m occurs on subchannel C_m in slot n. Let us focus on CTE_m. Suppose that node r is selected as the j-th relay $j = 1, \dots\dots, \hat{k}_m - 1)$ during slots $(n+k)(\hat{k}_m \geq k_m)$. Note that k may be different than j, since according to [4], multiple relays can be used in the same slot.
The value of k is determined by the availability of subchannels and the subchannel allocation scheme. If r was a source node during the collision slot, it will simply retransmit its packet at a subchannel that is selected according to some rule (not necessarily on C_m). Otherwise, it will transmit over C_l, the signal that it received during slot n over C_m. Since relays use different subchannels or slots, their transmissions do not overlap. Therefore, each relay transmission provides the BS with a linear equation that contains the initially collided packets.

Without loss of generality, let us assume that among the $\hat{k}_m - 1$ nodes, the first η nodes are source relays, and the next l nodes are non-source relays. It holds $\eta + l + 1 = k_m$.
Let us form a matrix, Z, $(B \times k_m N)$, whose first block column is the packet received at the BS during the collision slot, and subsequent blocks are packets from relay transmissions received at the base station during CTE_m .
It holds:

$$Z = \mathbf{X}^m H + W \quad (8)$$

where, $\mathbf{X}^m$ is a $(B \times k_m N)$ matrix based on the packets of users that collided over C_m.
H is a $(k_m N \times k_m N)$ channel matrix.
W is a $(B \times k_m N)$ matrix formed based on the noise at the BS during the collision slot, and each subsequent retransmission.

Collision Detection

For collision detection we need to include a user ID in the packet of each user, with ID's being orthogonal between different users. To maintain orthogonality of IDs despite the channel, ID symbols are distributed as follows:
All will be on the same carrier, and will be distributed one in each OFDM block. For example, for some j, the columns $j, j + N, \ldots\ldots, j + K_m$ of matrix $\mathbf{X}^m$ will contain the orthogonal IDs of users, $i_1, i_2, \ldots\ldots, i_{K_m}$ respectively. After extracting the j-th column of Z and performing cross-correlation with the known user IDs, we can determine whether a user is present in the collision by comparing the cross-correlation result to a threshold [5].

Channel Estimation

For channel estimation we need to include a number of pilot symbols in each packet of each user. At least one OFDM symbol full of pilots is needed.
Let S be the row selection matrix that selects rows of Z containing pilots. Then,

$$\mathbf{SZ} = (\mathbf{SX}^m)\mathbf{H} + \mathbf{SW} \quad (9)$$

where, $\mathbf{SX}^m$ contains pilots only. We can obtain a least square solution of H as $(\mathbf{SX}^m)^H \mathbf{SX^m}]^{-1}(\mathbf{SX}^m)^H \mathbf{SZ}$. Once the channel matrix $\mathbf{H}$ is estimated, the transmitted bits over C_m can be obtained via a ML or ZF equalizer as in [5].

SIMULATION PARAMETERS

The proposed schemes are programmed and simulated in MATLAB software. Consider a network with total users, J = 32, and each user is equipped with a buffer of infinite size. The users' ID sequences are selected based on the rows of a J-th order Hadamard matrix. The IDs are used to estimate the number of users involved in a collision. The frequency selective channel has L = 3 taps. Each tap is chosen independently from the sum-of-sinusoids simulation model for Rayleigh fading channels of [6]. The number of OFDM carriers is 64, and only 48 carriers are used to transmit data packets. The OFDM symbol duration is 4 µs and the guard interval is 800 ns. Each packet contains 1000 OFDM blocks, and its duration is 4.8 ms. QPSK modulation is used. The channel matrix is estimated using pilots with 32 OFDM symbols. The SNR is 20 dB. Packets received at the base station with BER higher than 0.02 are considered lost or corrupted.

RESULTS AND DISCUSSION

Performance of Scheme A and Scheme B

The throughput is defined as the average number of packets that are successfully transmitted in one time slot, normalized by the number of subchannels M. Each user is fed with a Poisson source with rate λ large packets per slot, so the total traffic load of the system is λJ. The total simulation time is 2000 slots, and performs 20 Monte-Carlo experiments.

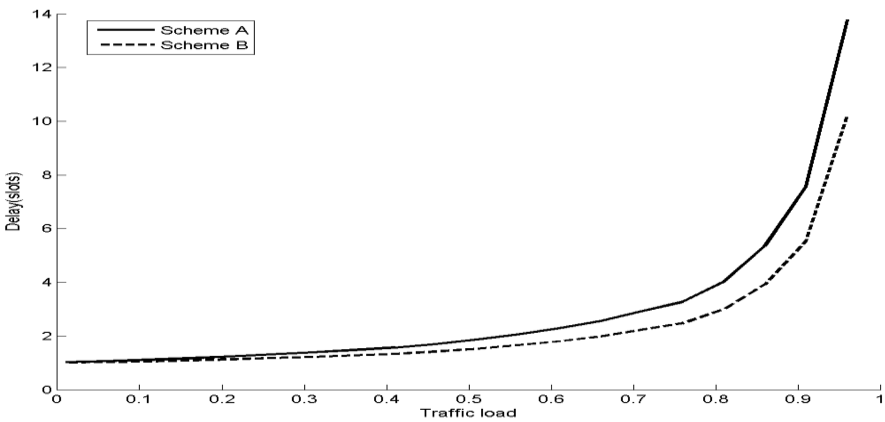

Fig. 1 Delay of Scheme A and Scheme B

In Figure 1, the delay performance of Scheme B, as compared with A is shown. Both schemes exhibit the same throughput as it can be seen in Figure 2, where a ML equalizer is used.

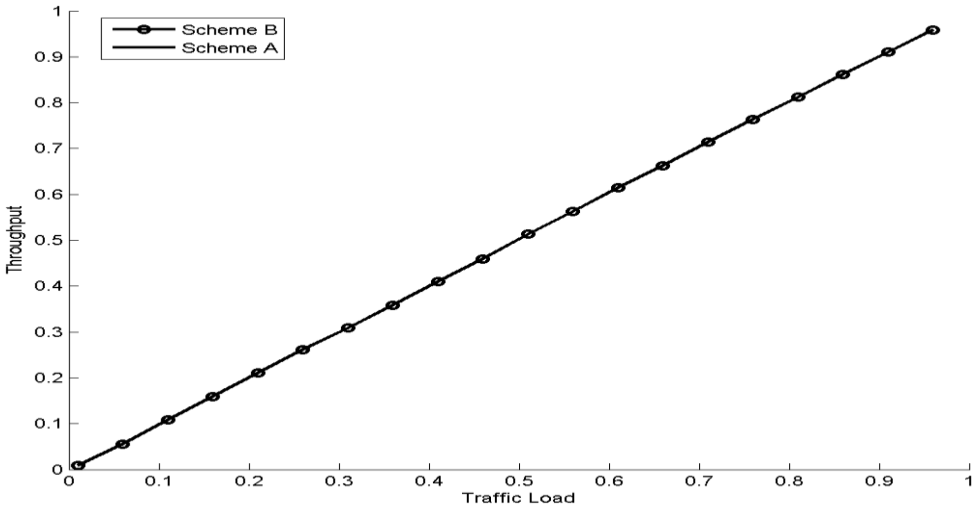

Fig. 2 Throughput of Scheme A and Scheme B

Experimental Deduction and Comparison

Here, a multichannel extension of cooperative protocol – a cross layer cooperative protocol for collision resolution in data networks was studied. For Scheme A, collision on subchannel C_m involves subchannel C_m only whereas the Scheme B resolves a collision on C_m by using all the available subchannels were studied and showed that Scheme B achieves shorter delay than Scheme A.

Table-2 Experimental Analysis of Cooperative Relaying

Cooperative Relaying	**For a system consisting**			
	2 subchannel	**3 subchannel**	**4 subchannel**	**5 subchannel**
Scheme A	3 slots	4 slots	5 slots	6 slots
Scheme B	2.5 slots	5 slots	8.5 slots	13 slots

After executing the subchannel allocation framework developed by [1]; we found that the average processing time for 2 subchannels, 3 subchannels, 4 subchannels and 5 subchannels are 2.5 slots, 5 slots, 8.5 slots and 13 slots respectively.

Table-3 Experimental Analysis Based on Scheme C

After employing hypothetical consideration	**For a system consisting**			
	2 subchannel	**3 subchannel**	**4 subchannel**	**5 subchannel**
Scheme A	3 slots	4 slots	5 slots	6 slots
Scheme B	2.5 slots	3.66 slots	4.75 slots	5.8 slots

Our endeavour in this paper was Scheme C where the shared subchannels are used to resolve collision irrespective of the adjacent slot to resolve collision on a particular subchannel. Table-3 shows the average processing time for 2 subchannels, 3 subchannels, 4 subchannels and 5 subchannels are 2.5 slots, 3.66 slots, 4.75 slots and 5.8 slots respectively. Therefore, upon the implication of the hypothetical consideration i.e. Scheme C, it was found that the performance of the system was much improved.

CONCLUSION

In this paper we presented an improved scheme so as to resolve collision on the collision resolution areas of the data networks. Two schemes namely Scheme A and Scheme B were studied [1], and showed that Scheme B can achieve shorter delay than Scheme A. To defeat the problems of cooperative communication, we developed an improved Scheme C which holds bandwidth efficiency. The experimental analysis shows that for a consecutive increase in the subchannel - there is a significant increase in the processing time in comparison to subchannel allocation framework developed in [1].

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