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Data sharing among wireless client devices in cooperative manner with minimum transmissions

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Abstract A group of nearby wireless end devices such as mobile phones can benefit a fast service to satisfy their required packets by cooperating to exchange their packets after receiving from a common base station. This problem can be formulated as a coding and transmission scheme and solved by the linear network coding. We propose a balanced coding and transmission scheme called BCTS that will assign suitable clients to find and transmit linear combinations of the received packets. The goals of our scheme are to minimise the total number of transmissions and to maintain fairness among the participants in the cooperative group in order to maintain the limited energy resources until all members satisfy their needs. Moreover, we also introduce transmission scheme with physical layer network coding (BCTS/PNC) for the same problem to further reduce the required transmission time slots and accomplish the data exchange process in short completion time. We present the performance of the schemes and discussion in terms of the fairness, the number of transmissions and the completion time by testing with various simulation parameters and scenarios.

Keywords Cooperative data exchange · Linear combination · Physical layer network coding · Wireless multi-hop networks · Fairness

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1 Introduction

With the help of advanced information and communication technologies, the daily life of a person in this 21st century modern society becomes easy for getting contacts around the world or accessing the latest information which takes an important role for the success of an individual or a company. The invention of computing machines are also enhanced from the generation of supercomputers to the today's smart phones which already possess the processing and storage capacities of the earlier computers. Nearly every body in modern society possess a smart phone. A smart phone becomes an essential partner for most of the people to make their daily activities easy from accessing information to setting an alarm for waking up at the start of a new day. The conventional way of communication between two mobile wireless devices such as smart phones and laptops is through a base station which usually locates at a far distance because of the high expense of building towers for both cellular and WiMAX wireless base stations. An interesting problem scenario is the direct data sharing among the wireless client devices that are located in the vicinity of each other to reduce the amount of expensive communication to a far base station.

Assuming that some nearby wireless client devices download a file from a common base station. Some devices may receive the whole file while some receive only a portion of it and lose other subset of the file because of the poor wireless links between the base station and them. In this case, the nearby wireless devices can utilise the advantage of short-distance communication links by creating a cooperative data sharing group among them via the built-in Bluetooth or Wi-Fi interfaces like in (Heidarzadeh and Sprintson, 2015; Keshtkarjahromi et al, 2015; Rouayheb et al, 2010; Zhang et al, 2012). With this approach, devices will possess a faster and reliable short-range communication service to fulfil their requirements and no need to request to a far base station with slow connection again. The base station will also be able to serve other users because all the n packets of the file are transmitted to the group. The clients only need to collectively possess n packets within their group and want to cooperate to share the packets they have already received. Cooperation between neighbouring nodes can provide many benefits such as energy saving of a device by means of sharing the load among them, bandwidth saving and low delay services because the expensive long-distance cellular links are free for another users. Moreover, the overall throughput of the network can be increased by exploiting the broadcast nature of the wireless medium. (Mohammad, 2013; ScienceDaily, 2015) predict the cooperative communication to become one of the major features for the emerging fourth and fifth generation wireless systems. In our work, we focus on the fairness among the peers based on the number of transmissions they make while maintaining the minimum number of transmissions as a whole. The reason is that energy saving is important not only for the whole data exchange process but also for each individual participant. If a client which possesses an independent packet runs out of energy quickly, other clients will not satisfy their needs and the data exchange process will not accomplish with the assumption that client devices collectively possess all packets from the base station.

The main contributions of our paper are: we propose a balanced coding scheme based on the index and linear network coding and a data transmission scheme with physical layer network coding for the cooperative data sharing scenario. The proposed schemes consist of algorithms for the selection of next transmitter and selection of best linear combination. The algorithm will maintain the fairness among nodes by distributing the number of transmissions they make while maintaining the number of transmissions to be minimum. In this algorithm, each client changes the role of transmitter and receiver based on the reception knowledge they keep in information table in each round of data transmission. This paper is the extension of our previous work (Lin et al, 2016). In this paper, we add the scalability of the algorithm for the increasing number of packets. When the number packets involved in one generation of data exchange process is high, the computation for the coding and decoding of the coding scheme that minimises the number of transmissions will become burden for a mobile node. We also provide the buffer management of incoming and outgoing packets, local encoding and decoding for their combinations. Some consideration on the addition of two packets which have different lengths is also included for the transmission scheme with physical layer network coding. In consideration of those problems, in this paper, we consider more general scenario for the data exchange among the wireless nodes for example, a router, a node in an ad-hoc network or wireless mesh network, that have high processing and memory resources for computing and buffer requirements.

The rest of the paper is organised as follows. Some related work is discussed in Section 2. We describe a scenario of the cooperative data sharing and the cooperative coding scheme with example illustration in Section 3. The detailed description of the proposed balanced coding scheme and the algorithm is presented in Section 4. Section 5 presents the introduction of physical layer network coding (PNC) into the data exchange problem. Simulation and discussions of the results are presented in Section 6 and 7 respectively. Finally, Section 8 is the conclusion of the paper and some hints for future work.

2 Related works

With the application of linear network coding (Fragouli et al, 2006), the benefits of cooperation can be further considered for the data exchange problem because many devices can simultaneously gain from one linearly coded packet (linear combination) transmission. We assume that mobile devices are within transmission range of each other and they can hear the broadcast transmission from each other successfully. In this linear approach, the bits of each incoming packet is replaced by the symbols over the finite field $GF(2^n)$ and forms a vector of symbols. A client device creates linear combination of its packets and choose one combination to be transmitted that will benefit the other peers. The operations are performed over $GF(2^n)$. As other peer nodes in the cooperative group may already have some independent packets, they can recover a new one after performing Gaussian elimination of the received packets.

The problem of selecting an encoding scheme that will minimise the number of transmissions is referred to as index coding. The index coding problem in (Chaudhry and Sprintson, 2008), where a central base station performs the transmissions of linear combined packets to make other clients satisfy their requirements. The difference is that, in cooperative approach, all of the clients involve in the transmission process. In this category, many existing research works such as (Courtade and Wesel, 2014; Rouayheb et al, 2010; Sui et al, 2016; Tajbakhsh and Sadeghi, 2012) mainly studied the optimum number of transmissions to reduce the complexity, overhead and delay until all clients ultimately recover the required packets. They formulated the problem into integer programming and proved that it is NP-hard.

The authors in (Rouayheb et al, 2010) formulated a lower and upper bound on the number of transmissions needed to satisfy the requirements of all clients and showed that their algorithm performs closer to the lower bound by a numerical simulation. They choose a candidate client which possesses the maximum number of received packets as a transmitter for next round. If there is more than one candidate client, their scheme choose the next transmitter randomly. They did not consider fairness on the number of transmissions each client makes in their work.

3 Scenario of cooperative data sharing

The scenario of a cooperative data sharing is shown in Figure 1. Some nearby mobile devices download a file from a common base station which may be located at a long distance. After the packets for the file are transmitted by the base station, some client devices only receive some subset of the packets but all the nearby nodes collectively receive all the packets. The problem is to satisfy the requirements of all peers in the cooperative group by sharing each other via the local wireless connections, needing no request to the far base station. This problem can be solved by a cooperative linear network coding scheme. For the basic understanding of a cooperative linear network coding scheme, we will use the scenario of Figure 1 and the information in Table 1 as an example to explain how it works . At the initial state in the the cooperative group with four clients, clients c_1 and c_3 have received five packets out of six and are the one that have maximum number of received packets. Client c_2 has received three packets and is the client with the least number of packets while client c_4 receives four packets. The linear network coding scheme calculates an encoded packet which is a combination of multiple packets from a client and transmits the encoded packet. Many other client devices with the requirement different packets can benefit from the same encoded packet.

In this example, the data exchange among four clients accomplishes with three coded packets transmissions; two transmissions: $x_1+x_2+x_3+x_4+x_6$ and $x_1+x_2+x_3+x_4+x_5+x_6$ from the maximum client, c_3 and one transmission: $x_1+x_2+x_3+x_5+x_6$ from the another maximum client, c_1. However, it should be more desirable that the coding scheme can distribute the transmissions among as many clients as possible in order to maintain fairness among them. As the clients will gradually increase the number of received packets iteration by iteration, the dependency between the encoded packet and the existing packets becomes higher. In this situation, choosing a client with the maximum packets will not provide significant improvement. Giving higher priority to a client which has less participation in the data exchange process will share the work of previous transmitters. As a consequence, a node with the maximum number of packets in the cooperative group can save its energy and computing resources. This is the contribution we provide in our proposed balanced coding scheme to keep fairness among as many client devices as possible.

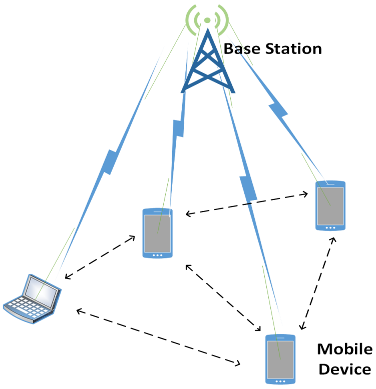


Fig. 1: Cooperative data sharing among the nearby mobile clients after downloading a file from a far base station.

4 Proposed balanced coding and transmission scheme (BCTS)

Many important steps comprise our proposed balanced coding scheme. We need buffers for the incoming and outing packets; coding and decoding operations together with the selection of a best combination; selecting a transmitter based on the knowledge of receiving packets at the clients and accessing a channel to broadcast a coded packet.

Buffer management at each node. We assign two buffers in each client device: one for the incoming packets and another for the outgoing coded packets. The recovered original packets will be stored in the permanent storage. At the start of a cooperative data sharing process, one or more peer devices will have received all or some of the packets from the base station. Therefore, the size of the incoming buffer is equal to the number of packets n and that of the outgoing buffer is equal to number of linear combinations based on how many packets are coded together and upper bounded by 2^{n-1}.

Reception information table for selecting next transmitter. Maintaining fairness among the participants of the data sharing group is one of our goals. We propose an algorithm which selects the transmitter for each iteration based on the number of packets each client node possesses, usually the client with maximum packets. Moreover, nodes should also take into account the number of transmissions they made in order to maintain the fairness among them as we explain in Sect.3. Our approach is to keep an information table like Table 1 in every node. At the start of data sharing process after receiving packets from the base station, all clients should broadcast reception information to announce their packet receiving status. Then a client node can use this knowledge for deciding a suitable transmitter for next round.

Coding and decoding. Then the successful client of previous step calculates the linear combinations of packets from the incoming buffer by using the encoding vectors and stores

Table 1: Example reception information table : received packets and transmissions made by each clients

Clients	Packets						Transmissions
	x_1	x_2	x_3	x_4	x_5	x_6	
c_1	1	1	1	0	1	1	1
c_2	1	1	0	0	0	1	0
c_3	1	1	1	1	0	1	2
c_4	1	1	0	1	0	1	0

the coded packets in the outgoing buffer before being sent. After each round of coded packet transmission, every node performs decoding operation of the incoming coded packet and the existing received packets. Then the clients update their information table and can easily decide who should take turn for transmission in next round until all the clients satisfy their requirements. This is possible due to the fact that all nodes exist within the transmission range and every node can hear the transmission from each other.

Medium access control (MAC) mechanism. The authors in (Zhang et al, 2007) used a method to turn a client device in master role (transmitter) to slave role (receiver) by sending the access request message for the Piconet-based distributed cooperative approach, which is similar to the data exchange problem here. In our approach, we do not need to change a client device from one role to another from time to time. We just need a simple MAC mechanism to access the channel to start a transmission. The winner for transmitter will broadcast a control message to access the channel and other clients refrain from transmitting for the specified duration.

Selection of best combination. In the linear data exchange scheme, each client has to calculate the receiving information to choose a suitable combination for the transmission. In principle, the client with the maximum number of packets possesses the best combination at earlier stages of the process as the dependency between the combination and the received packets at other peers is low. Selecting a best combination that can increase the dimension of the subspaces of as many clients as possible is one of the major goals of the algorithm. One major challenge for this job is the computational time required to find it for some cases depending on the distribution of the initial receiving packets. To overcome this challenge, we introduce a variable in our algorithm, which will control the number of clients that should increase their ranks of the subspaces. We derive the value of this variable by studying the relationship between the ranks of the subspace of each client after running the simulation many times. For those cases, the chosen combination might not be an optimum one. The condition and the value of control variable for picking the best combination is described in Algorithm 2.

4.1 Algorithm for balanced coding scheme

At each iteration of the algorithm, one of the clients broadcasts a linear combination of packets in its incoming buffer which are from the set $X = \{x_1, \cdots, x_n\}$ of n packets. For a coded packet x we denote by $C_x \in GF(2^n)$ the corresponding vector of linear coefficient, i.e., $x = C_x.(x_1, \cdots, x_n)^T$. We also denote by Y_i the subspace spanned by vector corresponding to the linear combinations available at client c_i. At the beginning of the algorithm, Y_i is equal to the subspace spanned by vectors that correspond to the packets in $X_i \subseteq X$, i.e., $Y_i = \langle\{C_x | x \in X_i\}\rangle$. The goal of the algorithm is to simultaneously increase the dimension of the subspaces $Y_i, i = 1, \cdots, k$, for as many clients as possible. At each iteration, the algorithm identifies a client $c_i \in C$ whose subspace Y_i is of maximum dimension. Then, client c_i selects a vector $b \in Y_i$ in a way that will increase the dimension of Y_j for each client $c_j \neq c_i$, and transmits the corresponding packet $b.(x_1, \cdots, x_n)^T$. At some iteration, the subspaces associated with a number of clients may become identical. We merge this group of clients into a single client with the same subspace.

Algorithm 1 Algorithm for balanced coding scheme

```
for $i$ = 1 to $k$ do
  $Y_i = \langle\{C_x | x \in X_i\}\rangle$
end for
while there is a client $i$ with dim $Y_i < n$ do
  while $\exists c_i, c_j \in C, i \neq j$, such that $Y_i = Y_j$ do
    $C = C \setminus \{c_i\}$
  end while
  Find a client $c_i$ with a subspace $Y_i$ of maximum dimension
  if there is only one $c_i$ then
    Select a vector $b_i \in Y_i$ such that $b_i \notin Y_j$ for each $i \neq j$
    Let client $c_i$ broadcast packet $x = b.(x_1, \cdots, x_n)^T$.
    Store $c_i$ as transmitter in the table
  else
    Find a client $c_j$ with a subspace $Y_j$ of maximum dimension
    Select the client that has less previous transmissions
    if $c_i$ is chosen then
      Select a vector $b_i \in Y_i$ such that $b_i \notin Y_j$ for each $i \neq j$
    else
      Select a vector $b_j \in Y_j$ such that $b_j \notin Y_i$ for each $j \neq i$
    end if
  end if
  Let client $c_i$ or $c_j$ broadcast packet $x = b.(x_1, \cdots, x_n)^T$.
  for $l$ = 1 to $k$ do
    $Y_i \leftarrow Y_i + \langle\{b\}\rangle$
  end for
end while
```

Algorithm 2 Algorithm for selecting best combination

```
if (number of other clients with $rank = max\_rank$) $\geq$ (number of other clients - 1) then
    Set control variable = 1
    Calculate best combination
else if (number of other clients with $rank \geq max\_rank - 1$) $\geq$ half of number of other clients then
    Set control variable = 2
    Calculate best combination
else
    Set control variable = number of other clients
    Calculate best combination
end if
```

5 Balanced coding and transmission scheme with physical layer network coding (BCTS/PNC)

In this part of our work, we extend our scenario to a more practical setting, in which we consider some nodes exist outside the one hop transmission range. We apply the concept of physical layer network coding (PNC) to the data exchange problem to help reduce the number of transmissions. The basic idea of PNC is to exploit the mixing of signals that occurs naturally when electromagnetic (EM) waves are superimposed on one another (Liew et al, 2011). The simultaneous transmissions by several transmitters result in the reception of a weighted sum of the signals at a receiver. We allow transmission from two clients in one round of the algorithm. Their addition will be relayed by an intermediate node. This weighted sum is a form of network coding operation by itself. One of the advantages of this transmission scheme is that the two transmitters can themselves benefit from the addition of coded packets. This is different from the previous approach in which the transmitter node cannot benefit itself from its transmitted coded packet. Another advantage is that transmissions from two clients is allowed in the same time slot and the number of required time slots can be reduced by the PNC. Relay is simply an intermediate node that receives the addition of combinations transmitted from the client nodes and broadcasts the coded packet back to the clients including the transmitters.

5.1 Algorithm for transmission scheme with PNC

We consider transmitting the addition of two linear combinations from two clients. When the packets to be combined do not have the same length, the shorter ones are padded with trailing 0s to make their lengths identical. The resulting encoded packets (linear combinations) have same length as original ones. First, our algorithm chooses a linear combination from the client with maximum number of packets. Then it finds another linear combination from the second maximum-rank client. These two combinations are transmitted simultaneously and allowed to add in the air naturally when electromagnetic (EM) waves are superimposed on one another. Relay node deals with the mapping of the mixed signal to the desired network-coded signal $S_R = S_1 \bigoplus S_2$. It broadcasts S_R to the other clients in second time slot. In the algorithm, we add two combinations first and then transmit the addition. If there is more than one client with the maximum number of packets, the two transmitters are carefully designated based on the information of their previous transmissions as in the balanced coding scheme.

This scheme has some problems to be tackled. Sometimes, the mixed signal results in no increment in the rank of the subspace of other clients. This is because the selected combinations from two clients have some linear dependence. For that situation, transmitting only one combination will be better solution. We analyse the performance of this approach by the numerical simulation in terms of the number of required time slots, the number of benefited clients in each round of algorithm and the minimum number of total transmissions.

Algorithm 3 Algorithm for transmission scheme with PNC

```
for $i$ = 1 to $k$ do
    $Y_i = \langle\{C_x | x \in X_i\}\rangle$
end for
while there is a client $i$ with dim $Y_i < n$ do
    while $\exists c_i, c_j \in Ci \neq j$, such that $Y_i = Y_j$ do
        $C = C \setminus \{c_i\}$
    end while
    Find a client $c_i$ with a subspace $Y_i$ of maximum dimension
    if there is only one $c_i$ then
        Find a client $c_j$ with a subspace $Y_j$ of smaller maximum dimension than $Y_i$
        Select a vector $b_i \in Y_i$ such that $b_i \notin Y_j$ for each $i \neq j$
        Select a vector $b_j \in Y_j$ such that $b_j \notin Y_i$ for each $j \neq i$
        Add two vectors, $b = b_i + b_j$
        Let client $c_i$ and $c_j$ broadcast packet $x = b.(x_1, \cdots, x_n)^T$.
    else
        Find a client $c_i$ with a subspace $Y_i$ of maximum dimentsion
        if dimension dim $Y_i$ = number of packets then
            Select a vector $b \in Y_i$ such that $b \notin Y_j$ for each $i \neq j$
        else
            Select a vector $b_i \in Y_i$ such that $b_i \notin Y_j$ for each $i \neq j$
            Select a vector $b_j \in Y_j$ such that $b_j \notin Y_i$ for each $j \neq i$
            Add two vectors, $b = b_i + b_j$
        end if
        Let client $c_i$ and $c_j$ broadcast packet $x = b.(x_1, \cdots, x_n)^T$.
    end if
    for $l$ = 1 to $k$ do
        $Y_i \leftarrow Y_i + \langle\{b\}\rangle$
    end for
end while
```

6 Simulation setup

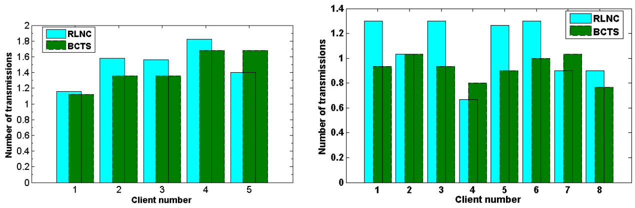
We created a computer simulation in MATLAB to study the performance of our algorithms and transmission in PNC scheme. We used the finite elements from $GF(2)$ for the index and linear network coding of each received and lost packet of each client for less complexity. In the simulation, we study the various aspects of performance metrics to evaluate the performance of our proposed schemes. A comparison of transmission in balanced scheme and the transmission without balanced scheme (i.e., nominating the next transmitter randomly) is studied. Then we study how the number of client nodes involved in the cooperative data sharing affect the fairness of the system. We also analyse the impact of initial packet receiving probability P_{init} to the system performance by using different probability values in each simulation with total 10 packets. We also investigate the number of time slots required by the BCTS/PNC scheme in our simulation. We study how PNC can help the data sharing process accomplish earlier than the scheme without PNC while the total number of time slots required is expected to be less. The performance of the whole coding scheme is studied with respect to the increasing number of packets and client devices in terms of scalability and fairness respectively.

Table 2: Simulation parameters

Parameter	**Value**
Hardware specification	IEEE 802.11a OFDM
Antenna type	Omnidirectional Antenna
Simulation environment	MATLAB 2014b
Initial packet receiving probability P_{init}	0.7, 0.6, 0.5, 0.4, 0.3
Number of packets	4 to 20
Number of clients	4 to 10
Finite field elements	$GF(2)$
Number of experiments	100

7 Results

This section presents the performance of the proposed balanced coding scheme and transmission scheme with PNC based on the results obtained from the simulation. We will discuss the number of transmissions from each client in the balanced coding scheme (BCTS), the number of clients whose ranks increase in each round of iteration in BCTS/PNC scheme and the total number of transmissions and time slots applied for the entire data exchange process. The results for each scenario are the values averaged over the 100 experiments for 5 clients downloading 10 packets from a base station with the initial receiving probability of 0.6.



(a) (b)

Fig. 2: Fairness based on number of transmissions from each client. Without balancing scheme, one or more clients have high number of transmissions. The proposed balanced coding scheme distributes the number of transmissions among the client devices. (a) For five client devices. (b) For eight client devices.

7.1 Comparison of balanced and conventional coding scheme

Figure 2 shows that our proposed scheme can significantly maintain the fairness on the transmission made by the clients participating in cooperative data exchange. In Figure (a), client c_4 is the only one client with the maximum number of transmissions. This condition disappears in the proposed balanced coding scheme (BCTS). The algorithm tries to balance the transmissions of the clients who possess similar number of packets. This can be easily seen in the transmissions of clients c_2 and c_3 make; and clients c_4 and c_5 compared to RLNC. But the client c_1 shows no significant change in the balanced scheme. This is because client c_1 is the client with the minimum number of packets received initially and it has least participation in the data exchange process. Client c_1 is receiver in most of the iterations. The results also show that the average number of transmissions in the proposed balanced coding scheme is even fewer than a conventional scheme without balancing capability. Figure (b) shows how fairness is affected by the increasing number of client devices in the cooperative group. When number of clients is greater, there is higher chance of less participation by many clients. This is also related to the number of packets they initially received. After transmissions from the clients with higher number of received packets, all clients may satisfy their needs.

However, the fairness of the system is not as good as that of BCTS when the PNC transmission is introduced into it as depicted in Figure 3. This is because a random intermediate node participates in forwarding the coded packets. From the standpoint of clients, they still need to involve in the simultaneous transmission and have to utilise their energy resources. The number of transmissions from each client is high and will have no big change.

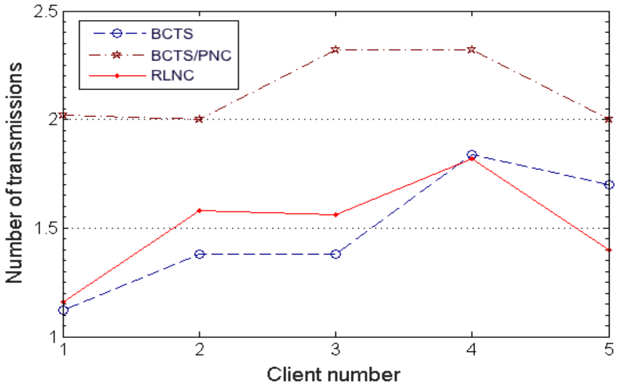
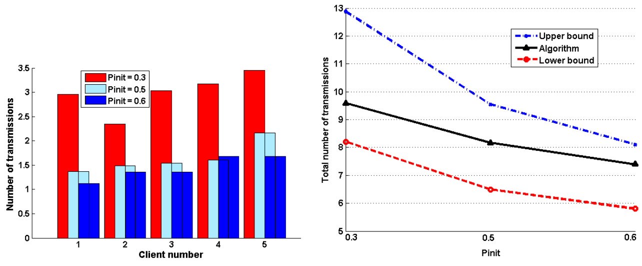


Fig. 3: PNC transmission scheme affects the fairness of the clients.

In Figure 4, we analyse the impact of the initial packet receiving probability P_{init} to the fairness of the proposed coding scheme and the total number of required transmissions. We show the results of three values of P_{init} with 0.3, 0.5 and 0.6. With P_{init}=0.3, the number of initial receiving packets is low and more number of transmissions are made than that of P_{init}=0.5 and P_{init}=0.6. The graphs show that the fairness of the system is better in higher values of P_{init} because the difference between two clients is very small.



(a) (b)

Fig. 4: Impact of initial packet receiving probability P_{init} for 5 client devices and 10 packets. (a) To fairness. (b) To number of transmissions.

7.2 Benefited clients in each round of data sharing process

The number of benefited clients in each iteration of the data sharing process is depicted in Figure 5. This value is high for BCTS/PNC scheme in earlier iteration, meaning that many client devices can recover their lost packets from the PNC-coded packets. The graph gradually declines with some fluctuation as the percentage of requirements of the clients decreases in later iteration. The graphs of BCTS and random scheme (RLNC) are especially high in the middle of the process. This behaviour can show that the PNC-coded packets can help increase the rank of the subspace of both the transmitters itself and the receivers. This is different from the BCTS and original scheme with no balancing (RLNC), where only the receivers can benefit from the coded packet in each round. This property can be clearly explained by the graphs: at time slot 1, BCTS/PNC scheme benefits more than 4 clients while the other schemes can only benefit at most four clients out of five. With the transmission with PNC, most of the clients devices including the transmitters increase their ranks in the earlier round of process. This helps the data exchange process to complete quickly satisfying the requirements of participants than the traditional transmission scheme while also ensuring that all the devices in the cooperative group recover their lost packets. Therefore, bandwidth and energy resources are saved.

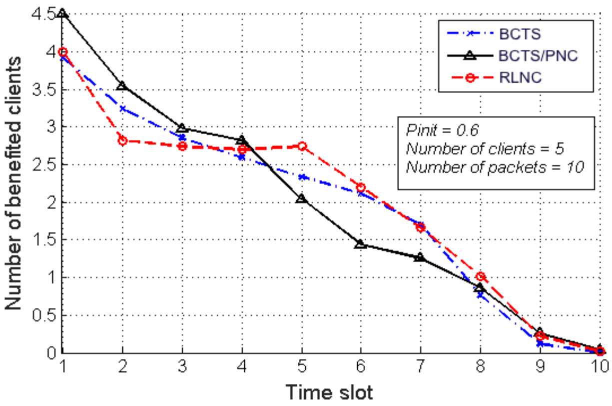


Fig. 5: The number of benefited clients in each iteration of the data sharing process. BCTS/PNC is better than the BCTS and RLNC without balance capability.

7.3 Scalability of the system when number of packets increase

The total number of transmissions required by the proposed schemes for the completion of one data exchange process is shown in Figure 6. Both the BCTS and BCTS/PNC schemes performs well because the number of transmissions is within the upper and lower bounds as defined in the reference paper (Rouayheb et al, 2010) and more than 50% less than the trivial bound. The BCTS/PNC scheme requires fewer number of transmissions than the BCTS balanced coding scheme for the higher number of packets. The proposed schemes also have better performance than the original scheme with random selection of transmitter as depicted in Figure 7.

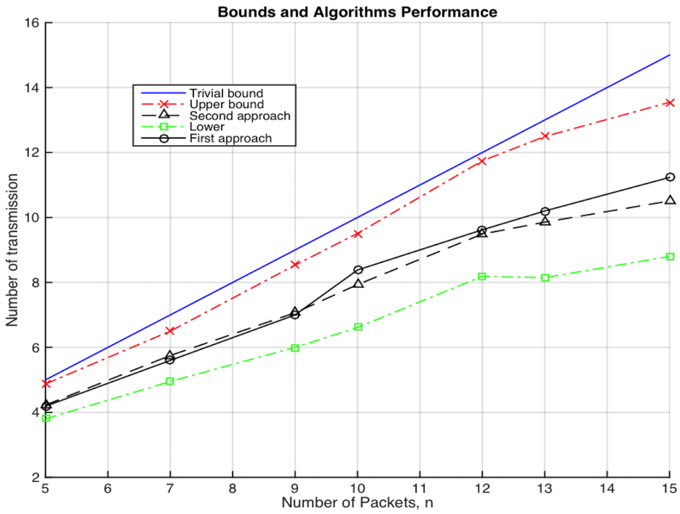


Fig. 6: Performance of the algorithms with the increased number of packets. The algorithms for both BCTS (first approach) and BCTS/PNC (second approach) schemes show a good performance result which lies closer to the lower bound on the required number of transmissions.

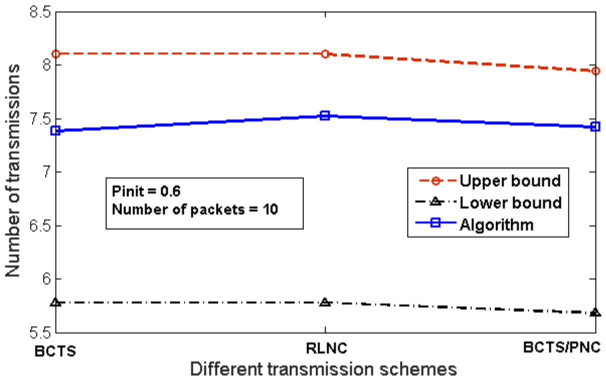


Fig. 7: Comparison of three different schemes with five clients, ten packets. The proposed schemes need fewer number of transmissions compared to the original one with random selection (RLNC).

8 Conclusions

In this paper, we proposed a balanced linear coding scheme and a transmission scheme with physical layer network coding for the data exchange problem to maintain the fairness among the client devices and to accomplish the process with minimum number of transmissions. Our schemes create an information table that keeps the packet reception information and the number of transmissions each client makes in each round of data exchange process. This knowledge is important to maintain fairness among the clients to ensure that a certain client does not run out of energy and leave the group. With our schemes, the total number of transmissions decreases while distributing the work load among the clients. Moreover, by allowing two clients to simultaneously transmit their linear combinations by the physical layer network coding, our simulation results show that clients receive their required packets mostly in the earlier iteration of the process. As a result, it satisfies the requirement of participants as quickly as possible and leads to the quick completion of data exchange process. The number of transmissions are within the lower and upper bounds and our algorithms maintain the scalability for the case of increasing number of packets. For future work, someone may consider the battery energy percentage of a node at the initial stage of data exchange process. This information will be useful in deciding the next transmitter and achieve more fairness to maintain the energy of the group as long as possible.

APPENDIX: Upper and lower bounds on the number of transmissions

In this section, the upper and lower bounds from (Rouayheb et al, 2010) are described.

The minimum number of transmissions is greater or equal to $n - n_{min}$ where n is the number of packets and n_{min} is the minimum number of packets held by a client, i.e., $n_{min} = \min_{1 \leq i \leq k} n_i$. If all clients initially have the same number of packets $n_{min} < n$, i.e., $n_i = n_{min}$ for $i = 1, \cdots, k$ clients, then the minimum number of transmissions is greater than or equal to

$$n - n_{min} + 1 \tag{A-1}$$

The upper bound on the minimum required number of transmissions is less than or equal to

$$\min_{1\leq i\leq k}\{|\overline{X_i}| + \max_{1\leq j\leq k}|\overline{X_j}\cap X_i|\} \tag{A-2}$$

for $|\mathbb{F}| \geq k$. Each client c_i initially holds a subset X_i of packets in $X = \{x_1,\cdots,x_n\}$, i.e., $X_i \subseteq X$. And $n_i = |X_i|$ denotes the number of packets initially available to client c_i, and $\overline{X_i} = X \setminus X_i$.

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