Cooperative MAC Design in Multi-Hop Wireless Networks—Part II: When Source and Destination are Two-Hops Away from Each Other

Hongzhi Jiao · Frank Y. Li

Abstract Ubiquitous and pervasive computing and networking are envisaged as part of the future 5G wireless communication landscape where devices which are multi-hops away from each other are connected in a cooperative way. In this paper, we investigate a challenging case in cooperative communications where source and destination are two-hops away from each other. From the perspective of MAC design, we propose a novel MAC protocol which enables two-hop cooperative communications by involving one or more one-hop neighbors of both source and destination as the relays for cooperative communication. To do so, a concept referred to as Multiple Relay Points (MRPs) has been introduced and the MRPs are selected by jointly considering the link quality of both hops. In addition to employing a static scheme which always uses a fixed number of relays for cooperative communication, we have also proposed an adaptive scheme which can optimally adjust the number of relays flexibly according to channel conditions. Through performance evaluation and comparison with the original IEEE 802.11 based scheme, we demonstrate that more reliable communications, reduced transmission power and significant throughput improvement can be achieved by using our two-hop cooperative MAC protocol, especially when operated in the adaptive mode.

Keywords 5G · Two-hop cooperative communication · MAC protocol · Relay selection

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1 Introduction

While 4G mobile communication is on its way towards standardization and commercialization, researchers are already envisaging the scenarios for further 5G wireless networks. Imagine the existence of ubiquitous wireless devices in such networks with or without infrastructure support and these diverse devices are spread in a distributed network with multi-hop communication capability. Cooperation communications with the help of different devices appear as a promising approach for improving system performance in such wireless communication paradigm.

Cooperation communications were originally proposed as a means to overcome unreliable transmissions by exploiting time, frequency and/or space diversity achieved from multi-paths. In a wireless network with multi-hops, a feasible solution to support cooperative diversity is to forward packets from source to destination by appropriately selected intermediate nodes. However, existing work [1–4] in this direction has traditionally focused solely on one-hop source destination cooperation under which a relay node R may help retransmitting a packet to the destination node D if the direct transmission from source node S to D fails [5]. A fundamental assumption for one-hop cooperation communication is that the transmitter can reach the receiver directly. Under this assumption, most existing MAC protocols are limited to a single one-hop source-destination scenarios, although few of them, e.g., [1] may also operate in a two-hop source-relay-destination manner if the one-hop direct transmission fails.[1] These schemes are not facilely further applied to a network topology where many multi-hop source-destination pairs exist.

In this paper, as an effort towards cooperative communication in multi-hop wireless networks, we propose a Two-hop Cooperative MAC protocol (TC-MAC) specifically designed for two-hop communications. A salient distinction between this work and existing cooperative MAC protocols is that in our scenario the source node and the destination node cannot hear each other, i.e., no direct communication between source and destination is possible. In other words, the communication between source and destination has to be forwarded via relay nodes which are one-hop neighbors of both source and destination. In TC-MAC, two working modes exist, i.e., *static TC-MAC* or *adaptive TC-MAC*. With static TC-MAC, the number of MRPs is always fixed [6]. Alternatively when the adaptive TC-MAC scheme is employed, the number of required relay nodes can be dynamically adjusted according to combined two-hop channel conditions. For example, as channel condition deteriorates, more relay nodes are selected in order to provide higher spatial diversity gain.

The rest of the paper is organized as follows. The system model is described in Sect. 2. After the relay selection algorithm is introduced in Sect. 3, the proposed cooperative MAC protocol is presented in details in Sect. 4. Performance analysis is then given in Sect. 5, and the performance is evaluated in Sect. 6. Finally the paper is concluded in Sect. 7.

2 System Model and Assumptions

As illustrated in Fig. 1, the system model consists of a source node, S, a destination node, D, and a number of intermediate relay nodes, i.e., $R_1, R_2, \ldots, R_n$, which may act as relays to retransmit data packets to destination node in a cooperative manner. The network in the model works in a two-hop fashion, which means that relay nodes $R_i (1 \leq i \leq n)$ are the one-hop neighbors of both source node S and destination node D; D is a two hop neighbor of

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[1] Indeed, the first transmission attempt in CoopMAC [1] is still one-hop direct communication.
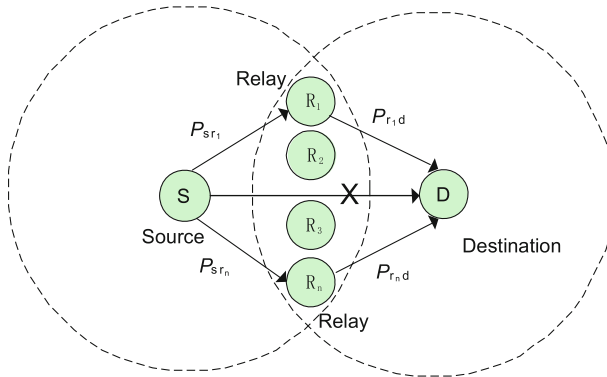
Fig. 1 System model for two-hop cooperative communication

S; and S cannot directly transmit data packets to D. In addition, relay nodes R_i do not have to hear each other, which means that they may be hidden terminals to each other.

In the system model, all channels are assumed to be independent of each other and the Packet Error Ratio (PER) for each channel is assumed to be uncorrelated for two consecutive transmissions. According to our protocol, each cycle of cooperative transmission will start from S to R_i, then followed by the transmission(s) of the same packet from R_i to D. Based on channel conditions the source node will make a decision on how many and which relays will forward the packets. Then all the selected relays will forward the packet to D, in a coordinated manner.

3 Relay Selection Algorithm

3.1 The Concept of Multiple Relay Point and Neighbor Information Acquisition

In contrast to the concept of Multipoint Relay (MPR) defined in Optimized Link State Routing (OLSR) [8] in which a one-hop neighbor is selected to forward packets to as many as possible two-hop neighbors, we introduce a concept of MRP in which one or more one-hop neighbors are selected as relays to forward packet to the same two-hop destination. While the purpose of using MPR is to reduce overhead for routing message broadcast in ad hoc networks, the idea of introducing MRP is to achieve spatial diversity in multi-hop cooperative wireless networks through multi-path transmissions by MRP nodes. As illustrated in Fig. 1, there exist n nodes which are one-hop neighbors of both S and D. However, only a selected number of potential relay nodes which satisfy the relay selection criterion belong to the forwarding set, MRP.

Under the proposed relay selection scheme, each source node must detect channel conditions to the destination node via all possible one-hop neighbor nodes. The same as in [8], the one-hop and two-hop neighbor information as well as their link quality status are obtained and maintained by exchanging HELLO messages between neighbors, in a proactive manner. Based on such a neighbor and link information database, the source node selects one or more neighbors which have the highest end-to-end link quality as the MRPs for its cooperative transmission.

The number of MRPs used for each cycle of cooperative transmission is determined based on channel condition obtained through HELLO messages. Upon receiving a HELLO message from a one-hop neighbor, a node is able to extract its two-hop neighbor information. Through the same procedure, the source node in our system model will know all one-hop and two-hop neighbors as well as the associated link quality. Consequently, a database including both neighbor and link information is established by the source node.

3.2 Multiple Relay Points Selection

Based on the established neighbor and link info database, a set of one-hop neighbors will be selected by the source node as the MRPs for cooperation communication. Since both of these two hops are important for end-to-end performance, we take link quality of both hops into consideration for MRP selection. An MRP set is composed of a selected $m (1 \leq m \leq n)$ number of nodes from n relay candidates which exhibit best combined link quality connecting source and destination. As an indicator, $h_i = \frac{2}{\frac{1}{|a_{si}|^2} + \frac{1}{|a_{id}|^2}} = \frac{2|a_{si}|^2|a_{id}|^2}{|a_{si}|^2 + |a_{id}|^2}$, indicates the combined link quality for an end-to-end link, where a_{si} indicates the link quality between source node S and relay node R_i, a_{id} indicates the link quality between relay node R_i and destination node D.

Based on the obtained h_i values for all possible paths between S and D, an m number of nodes with highest values will be selected as MRPs by the source node. When $m = 2$, for instance, the top two paths with highest h_i scores will be selected.

3.3 Optimal Number of MRPs and Transmission Order

With each specific channel condition, there will be an optimal number of MRPs which maximizes system performance. In order to obtain the optimal number of MRPs, we use the same method as in [9]. It is suggested that the best size of the cooperation group is around $\frac{1}{(1-P_{si})(1-P_{id})}$, where P_{si} is denoted as the probability of unsuccessful packet transmission in the primary channel between source and MRP candidates, approximatively taken as PER and P_{id} is the PER for the relay channel between the MRP candidates and destination. Since $\frac{1}{(1-P_{si})(1-P_{id})}$ is not a whole number in general, the optimal cooperation group size will be rounded to an integer.

Given the assumption in the system model that all channels are independent of each other, the received link quality is different from path to path among various relays. If channels exhibit high quality, then fewer MRPs are required, and vice versa. Considering the fact that each MRP experiences different channel condition resulting in a different number of required MRPs and that a large number of relay nodes may decrease transmission efficiency, we define the optimal number of MRPs according the relay candidate which provides the *best combined channel link quality* as

$$\text{Optimal number of MRPs} = \min \left\lceil \frac{1}{(1 - P_{si})(1 - P_{id})} \right\rceil, \quad i = (1, \ldots, n). \quad (1)$$

Note that the proposed cooperative protocol is operated on a single common channel, which implies that only one transmission can occur at any time. In order to avoid packet collision, the relay set should transmit the packet subsequently in a coordinated fashion and avoid simultaneous transmission of multiple MRPs.

In [7], a relay transmits the packet one by one according to its own measured timer. The relay nodes of which timer expires first will transmit the cooperative information. Due to

the uncertain values of the SNR for channel conditions which decide the value of the timer, it might be inefficient to use relay's own timer to transmit. For instance, two consecutive relays with approximate SNR values will send the packets in a short time interval, which may lead to packet collision. Hence, it is necessary to select a centric node, if possible, to fairly schedule the packet forwarding. With our system model, the source node is able to play such a central role. The strategy is that all relays will start to send the cooperative packet with a *constant time interval*, which means that there are m priority numbers for each relay node to access the channel. These priority numbers are derived from the combined link quality h_i. For example, the first and second relays in our scheme are selected as

$$h_1 = \arg_{\forall j} \max\{h_i\}, \ j \in \{\text{decoded MRP index}\},$$
$$h_2 = \arg_{\forall j} \max\{h_i\}, \ j \in \{\text{decoded MRP index}\}, \ j \notin \{h_1\}. \tag{2}$$

Unless two or more nodes have the same priority numbers, possible collision caused by cooperation could be avoided. In our scheme, we apply a method that compares the absolute value of h_i. Thus, the occurrence that two MRPs hold the same transmission order is avoided.

Based on the above description, a priority-based back-off counter for all MRP nodes is made according to their channel conditions. With this order pre-assigned, the relay node with the best channel quality will have the smallest priority back-off counter and forward the data packet first. While the first relay node is transmitting packet to the destination node, the other MRP nodes will detect that the channel is occupied and freeze their counter until the transmission finishes. The rest of the transmission procedures may be deduced by analogy. Consequently, by means of the priority order of MRP transmissions, it is feasible to avoid packet collision during the relay transmissions.

4 Adaptive Cooperative MAC Protocol Design

In this section, we present the proposed TC-MAC protocol with two alternative cooperative modes, i.e., the static cooperative scheme and the adaptive cooperative scheme, respectively.

4.1 The Static TC-MAC Cooperative Scheme

In the static cooperative scheme, if there is only one MRP required, the TC-MAC protocol works similar to the original 802.11 Distributed Coordination Function (DCF) scheme when used in the two-hop case, except that the random back-off mechanism in the second hop is replaced by a scheduled transmission from the relay node in our case. When more than one MRPs are required, the static TC-MAC scheme will work according to the message exchange sequences as shown in Fig. 2. Two MRPs are assumed here for the purpose of illustration. In brief, the static TC-MAC works as follows: (1) Obtain individual channel quality for both one-hop and two-hop links, and establish a neighbor and link database; (2) Calculate the overall two-hop combined link quality; (3) The source node decides which two MRPs will be used for packet forwarding; (4) The frame transmission sequence follows what is shown in Fig. 2.

When node S has packets to transmit, it starts to sense the channel. If the channel has been idle for a DCF Interframe Space (DIFS) period a data packet will be sent after S has completed the required back-off procedure. Due to the broadcast nature of the wireless communication, all nodes around S will overhear the packets, no matter it is MRP or not. However, only the MRPs will forward the successfully received data packets. Meanwhile, the Network
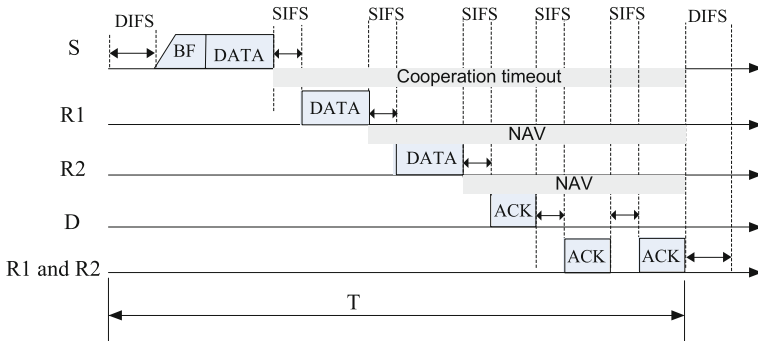
Fig. 2 Cooperative scheme by two MRPs

Allocation Vector (NAV) field associated with the transmitted and forwarded DATA frames will prevent possible transmissions of other nodes rather than S, R_i and D. As mentioned earlier and illustrated in Fig. 2, the transmission of the second relay happens immediately after the first relay finishes its forwarding with a Short Interframe Space (SIFS) interval, no matter the first relay transmission is successful or not.

In the presence of multiple relays, MRPs which are out of each other's sensing range may forward the packet during the same time interval, resulting in packet collision at the destination node. To avoid collision, each MRP will follow its transmission order instructed by the source node from its original DATA frame transmission. Consequently, each of them will start its own timer T_k proportional to the priority order to forward the DATA frame, as

$$T_k = (k-1) * (\text{SIFS} + T_{\text{DATA}}), \tag{3}$$

where T_{DATA} represents the time used for transmitting the DATA packet and k is the priority order. Since the relay nodes may not be able to hear each other, each MRP needs to calculate its starting instant for DATA frame forwarding. This is done by reading the Physical Layer Convergence Protocol (PLCP) header of the ongoing transmitting packet sent out by S, which contains the duration of the being transmitted DATA frame.

When R_i is forwarding the DATA frame, S will receive the implicit ACK by overhearing the data frame forwarded to D and decoding the header of the packet to compare with the original data packet. If it was the same packet that S just sent out, then S will know the MRP has already successfully received the packet.

After all relays have forwarded the data frame to D, the reception phase at the destination node will be performed and upon successful reception of the DATA packet, an ACK will be multicast to all MRPs. When the ACK frame sent by D is received, the MRPs will forward it to S. That is, a two-stage ACK process is needed in TC-MAC, due to the fact that S and D cannot hear each other directly. Again, the MRP with best channel condition will forward the ACK to S. Upon receiving one ACK, S could initiate another round of packet transmission. However, in case that S for any reason does not receive the ACK by R_1, the MRP with the second best path quality will start to forward the ACK according its priority order, after $(T_{\text{ACK}} + \text{SIFS})$. Although the redundant ACK may bring overhead for the protocol, it could increase transmission reliability. Correspondingly, as long as S receives one ACK, one cooperative transmission cycle is completed. However, if S does not get any ACK during time interval $m(T_{\text{ACK}} + \text{SIFS})$, a new cooperative transmission cycle will be initiated.

4.2 The Adaptive TC-MAC Cooperative Scheme

As discussed in Sect. 3.3, the optimal number of MRP nodes may vary as channel condition changes. In this subsection, we propose an enhancement to the static scheme by adaptively employing an optimal number of MRPs for each cooperative transmission cycle. The adaptive TC-MAC scheme could operate flexibly on both one MRP and a large number of MRPs. It works in a similar way as the static scheme does, but the difference is that the number of MRPs employed for each round cooperative transmission may vary in each transmission cycle. The adaptive TC-MAC scheme works as follows: (1) The same as the first two steps as in the static scheme; (2) The source node decides how many MRPs will be employed for the next transmission cycle as well as their transmission order; (3) The same as Step (4) in the static scheme; (4) For each new cooperative transmission cycle, go to Step (1), no matter the previous cycle is successful or not.

5 Performance Analysis

Similar to the IEEE 802.11 DCF scheme, the system time can be broken down into virtual time slots where each slot is the time interval between the instant when a packet is sent out from the source node and the instant when the packet is received at the destination node. The normalized system throughput, denoted as $\eta = E[B]/E[T]$, is defined as the successfully transmitted payload bits per virtual time unit, where $E[B]$ is the expected number of payload information bits successfully transmitted in a virtual time slot, and $E[T]$ is the expected length of a virtual time slot. $E[B]$ can be further expressed as: $E[B] = P_{\text{succ}} * L$, where P_{succ} is the probability of successful transmission and a function of per-hop packet failure probabilities, P_{si}, P_{id}, as explained below.

5.1 Analysis of the Original 802.11 DCF Scheme Operating in a Two-Hop Manner

When the original 802.11 DCF-based scheme is used in a two-hop transmission manner,[2] the total successful transmission time is the sum of time duration at Hop 1 and Hop 2, which are calculated below, respectively. It is worth mentioning that there is a back-off period in each hop in this case. This means that the relay node has to compete with other nodes for channel access before it forwards the DATA frame to D.

$$E\left[T_{\text{succ}}^{\text{orig}}\right] = T_{\text{hop1}} + T_{\text{hop2}} = 2 * (T_{\text{DATA}} + T_{\text{ACK}} + \text{DIFS} + \text{SIFS}) + E[T_{\text{BF}_1}]$$
$$+ E[T_{\text{BF}_2}]. \tag{4}$$

In the above equation, T_{BF_1}, T_{BF_2} is the back-off time duration of the transmission starting at the source and relay node, respectively. Furthermore, we assume that the packet is successfully transmitted by a relay node R, then the probability of successful transmission in this path will be

$$P_{\text{succ}}^{\text{orig}} = (1 - P_{sr}) * (1 - P_{rd}). \tag{5}$$

Finally, the throughput for the original scheme can be obtained by inserting $P_{\text{succ}}^{\text{orig}}$ and $E\left[T_{\text{succ}}^{\text{orig}}\right]$ into the expression η.

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[2] We assume that S, R_i and D are roughly synchronized in the calculation.

5.2 Analysis of the TC-MAC Cooperative Protocol

Without loss of generality, we study the performance of the cooperative scheme by using two MRPs, and then extend the results to more MRPs. Eventually, we derive the performance of the proposed adaptive cooperative scheme based on the static scheme. According to the MAC design in Fig. 2, the total successful transmission time of an ideal cycle is calculated in a two-hop manner, defined as $T_{\text{succ}}^{\text{coop}}$. Note that different from the original 802.11 scheme, there is only one back-off period during the whole transmission cycle in TC-MAC, which is executed at the source node. Therefore, $T_{\text{succ}}^{\text{coop}}$ can be obtained as

$$E\left[T_{\text{succ}}^{\text{coop}}\right]_{2-\text{MRP}} = 3 * T_{\text{DATA}} + 2 * T_{\text{ACK}} + 4 * \text{SIFS} + \text{DIFS} + E[T_{\text{BF}}], \quad (6)$$

$$P_{\text{succ}}^{\text{coop}} = 1 - [1 - (1 - P_{sr_1}) * (1 - P_{r_1 d})] * [1 - (1 - P_{sr_2}) * (1 - P_{r_2 d})], \quad (7)$$

where $P_{\text{succ}}^{\text{coop}}$ denote the probability of successful transmission in TC-MAC with two MRPs.

Similarly, we could extend the analytical result to cases with more than two MRPs in cooperation. The successful transmission time of one ideal cycle by one source node and m MRPs will be

$$E\left[T_{\text{succ}}^{\text{coop}}\right] = (m + 1) * T_{\text{DATA}} + 2 * T_{\text{ACK}} + (m + 2) * \text{SIFS} + \text{DIFS} + E[T_{\text{BF}}], \quad (8)$$

$$P_{\text{succ}}^{\text{coop}} = 1 - \prod_{i=1}^{m} [1 - (1 - P_{si}) * (1 - P_{id})], \quad (9)$$

where m is the number of MRPs, $P_{\text{succ}}^{\text{coop}}$ is the probability of successful transmission through these paths. Finally, the throughput performance of the adaptive TC-MAC protocol is the upper envelop among the curves which represent the performance with 1, 2, …, m numbers of MRPs for each range of SNR.

6 Performance Evaluation

We compare the throughput performance of TC-MAC operating on both the static and the adaptive modes with that of 802.11 in a two-hop network scenario. The network topology is the same as shown in Fig. 1. The payload length is set to be 500 bytes. The length of the MPDU header and ACK packet are 24 and 14 bytes, respectively. All the other default parameters in this study are configured according to the IEEE 802.11a standard. For every cycle of cooperative transmission, different number of potential relay nodes are generated to connect the source node and the destination node. The channels between any two transmission pairs are modeled as Rayleigh fading channel, independent of each other and with identical PER.

To compare the throughput performance between TC-MAC and two-hop DCF, we have defined a specific performance indicator as the ratio between η^{coop} and η^{orig}, as $\alpha = \frac{\eta^{\text{coop}}}{\eta^{\text{orig}}} = \frac{P_{\text{succ}}^{\text{coop}} * E\left[T_{\text{succ}}^{\text{orig}}\right]}{P_{\text{succ}}^{\text{orig}} * E\left[T_{\text{succ}}^{\text{coop}}\right]}$. When α is plotted in our performance evaluation curves, it indicates that the proposed scheme outperforms if $\alpha > 1$. On the contrary, if α is smaller than 1, the original scheme performs better.

6.1 System Throughput Based on Different Channel Conditions

Figure 3 depicts the obtained system throughput based on different channel conditions, both with the adaptive TC-MAC scheme. One of the curves is obtained based on the best relay
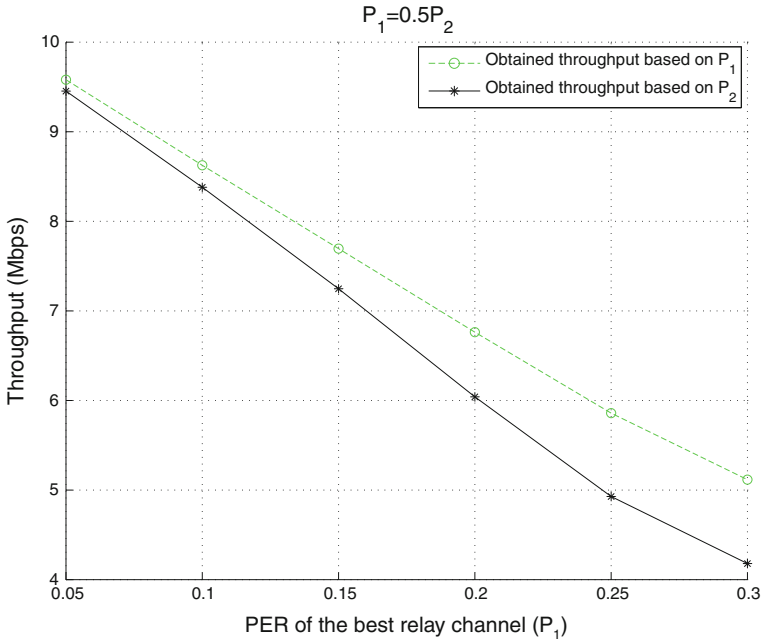
Fig. 3 System throughput based on different channel conditions

channel, while the other one is achieved by a poorer quality relay channel with a PER twice as high as the other case. As explained earlier, different channel conditions will lead to different optimal number of MRPs when adaptive TC-MAC is used. From this figure, it is easy to find that the system throughput based on a better relay channel will always achieve higher throughput. Furthermore, the difference between these two curves becomes smaller as channel conditions improve. On the other hand, as channel condition deteriorates, there is an apparent decrease in the slope for both curves. The one based on the poorer relay channel decreases more quickly.

6.2 Throughput Comparison: Static Versus DCF

The throughput of the static TC-MAC protocol with $m = 1, 2, 3$, respectively is illustrated in Fig. 4, in comparison with the original DCF scheme when used in two-hops. One can easily observe that in most cases the proposed static TC-MAC scheme outperforms the original DCF mechanism with respect to the obtained two-hop system throughput. This is because that the benefits introduced by our scheme are achieved not only from the reduction of transmission time but also from the spatial diversity exploited.

More specifically, if the channel condition is very good, e.g., PER < 0.16, the scheme with 1-MRP will perform best. This is because that one transmission per hop would be sufficient for the successful reception of the DATA packet over two hops. When PER is somewhere between 0.16 and 0.80, employing multiple MRPs would lead to better performance. For instance, when the packet error rate is 0.3, the throughput is enhanced by 72% with the two MRPs cooperative scheme. On the other hand, if the channel is almost error-free, i.e., PER is close to zero, the scheme with three MRPs has lead to lower throughput than the legacy DCF
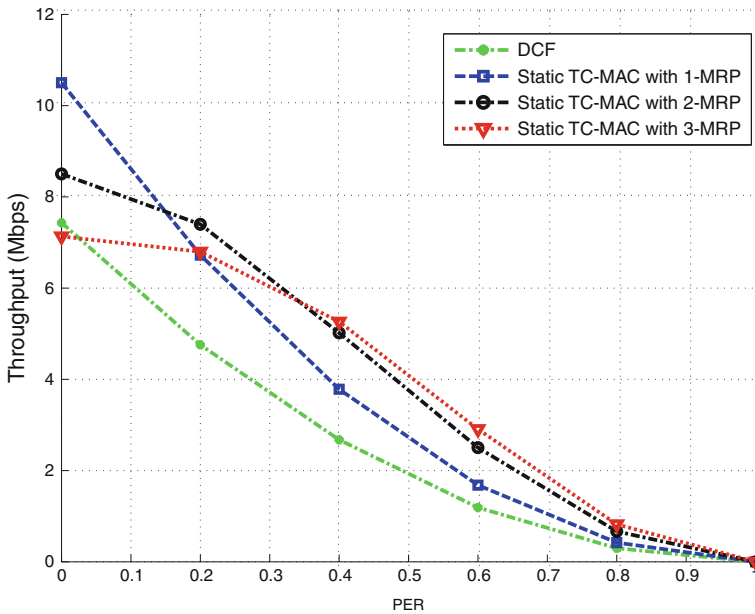
Fig. 4 Throughput performance comparison: original versus static cooperative

scheme. This is because too much protocol overhead is introduced with three MRPs since the destination node will wait until all three forwarded copies have arrived before decoding.

Furthermore, if the optimal number of MRPs is equal to or larger than 3, the throughput gain will increase but not significant anymore. It is observed that when the PER is higher than 0.35, the achieved throughput by the 3-MRP scheme is higher than that of the 2-MRP scheme, but not much higher. This observation indicates that the benefits may be comprised by the protocol overhead if too many relays are employed. In the worst case where the PER is extremely high, almost zero throughput is achieved for all schemes because all paths failed to deliver data.

6.3 Throughput Comparison: Adaptive TC-MAC Versus Static TC-MAC

Figure 5 shows the throughput gain of the proposed TC-MAC schemes versus DCF, by using α as the performance indicator. Again, the curves demonstrate that the static scheme with one-MPR and two-MRP always have higher two-hop throughput, which means that the cooperative MAC mechanism works more efficiently than the original DCF scheme. When dividing the SNR values into several regions, we observe that the three-MRP scheme exhibits higher throughput gain than the other schemes in the low SNR regions. In the high SNR regions, the one-MRP scheme will perform best, as shown on the right-side hand of Fig. 5. Based on these observations, the adaptive TC-MAC scheme always takes the advantage of the best envelop of the curves derived from the static numbers of MRPs. In other words, we could always get maximum throughput gain under any channel conditions when the adaptive TC-MAC scheme is employed.
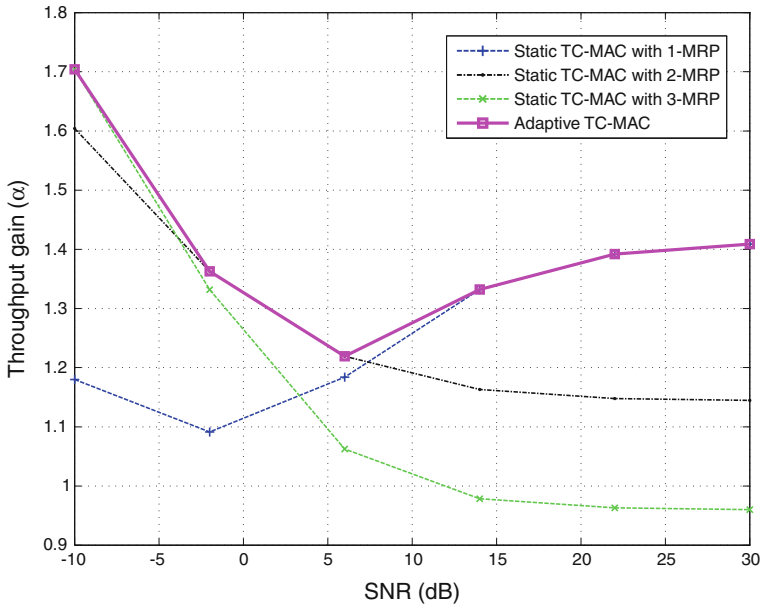
Fig. 5 Throughput gain of TC-MAC compared with IEEE 802.11 two-hop transmission

6.4 Achieved Throughput Versus Transmission Power

Figure 6 illustrates the required average SNR versus throughput for the adaptive TC-MAC scheme, the static scheme with two-MRPs and the DCF scheme in a two-hop transmission scenario. As shown in the figure, in order to obtain the throughput level at 6 Mbps, the scheme with two-MRPs requires only an average SNR of around -5 dB, while the DCF scheme requires an SNR of 3 dB. With the adaptive TC-MAC, moreover, only -6 dB SNR would be sufficient to provide the same level of system throughput.

Furthermore, lower SNR requirement can be interpreted as lower transmission power requirement. Given that the network topology and channel conditions are the same for all schemes in our performance evaluation, this result demonstrates that the required transmit power can be greatly reduced to reach the same throughput performance when the proposed TC-MAC protocol is used.

7 Conclusions and Future Work

Multi-hop networks exhibit a constituent paradigm in the picture of future 5G wireless communication landscape. In such an application scenario, how to perform cooperative communication among wireless devices which are multi-hops away from each other becomes a challenging task. The main contribution of this work is that a two-hop cooperative MAC protocol which deals with the case of no direct communication between the source and destination nodes has been proposed. The study investigates the trade-off between the number of relay nodes and channel conditions in order to take full advantage of spatial diversity for system performance improvement. The numerical results demonstrate that compared with the non-cooperative and the static cooperative schemes, significant throughput improvement
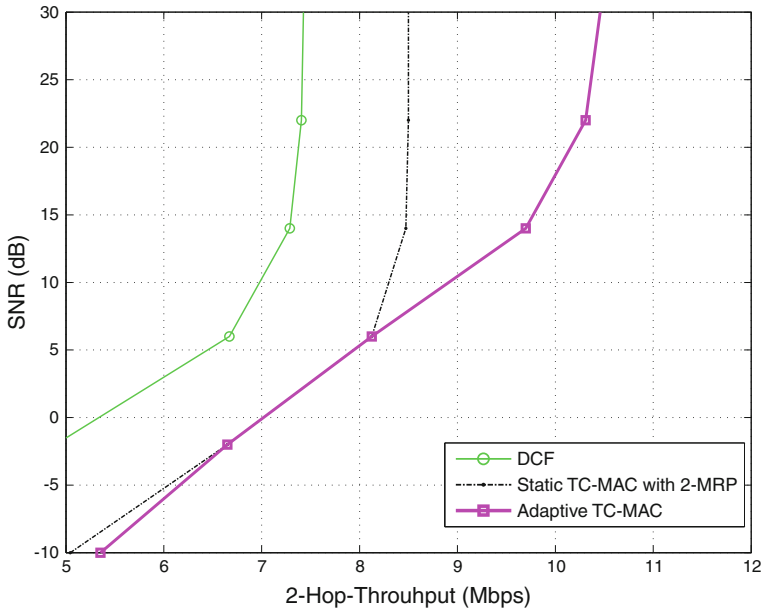
Fig. 6 Average SNR versus throughput

can be achieved by employing a dynamic number of relay nodes for cooperative communications. How to extend TC-MAC into larger-scale multi-hop wireless networks as well as studying its performance remain as our future work.

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