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# A Proxy Cooperative Diversity Method based on IEEE 802.11 Standards

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## ABSTRACT

Cooperative communication techniques have been proposed in order to improve the quality of the received signals at the receivers by using the diversity added by duplication of signals sent by relays situating between each transmission pair. This paper proposes a new on-demand cooperative transmission technique concerned with the interoperability issues between nodes with cooperative functionality and legacy nodes. Based on the standard IEEE 802.11, the proposed method can switch its transmission mode for each data frame between a cooperative mode and a non-cooperative mode automatically. Moreover, it can work with the IEEE medium access method in the basic mode and in the optional RTS/CTS mode. An original method is proposed, where the relay node acts as a proxy that is in charge of data retransmissions when needed. Interest of the proposition is to improve the transmission performance by decreasing the number of retransmissions due to frame errors. Moreover, the proposition avoids inappropriate routing processes that are costly in time and bandwidth. Evaluation of the proposition is done by simulation. Analysis of the results is mainly based on the Packet Delivery Ratio (PDR) and on the Number of Route Discovery and Maintenance (NRDM) per second.

## Categories and Subject Descriptors

C.2.1 [Computer-Communication Networks]: Network Architecture and Design – *wireless communication*

**General Terms:** Algorithms, Design, Performance.

**Keywords:** Cooperative communications, IEEE 802.11, Proxy diversity.

## 1. INTRODUCTION

In wireless communications, effects of fading make a large variation in the power of the received signals causing adverse effects to the link quality. The fading causes errors on the data packets that generate the activation of recovery processes in the upper layers of the network. Thus, in multi-hops environment, the routing process in charge of path recovery is triggered in case of link failure. Due to the time variation of the link quality, these recovery actions would be not appropriate. To tackle with the

wireless environment variability, a solution adopted by many protocols designers is to propose some adaptive solutions based on cross layer mechanisms. For example, a link layer mechanism for the retransmissions is introduced by some awareness at the upper layers. Another solution is to increase the link quality by increasing the signal diversity, as cooperative communications can do. Inspired from MIMO (Multiple Input Multiple Output) systems, the global idea is to transform the neighbor nodes in multiple antennas that help the source by relaying its data. Thus, it gains the signal diversity at the receiver and reduces its bit error rate [1]. In this paper, we propose an original method, which is a hybrid of these two approaches. It is a cross layer mechanism that improves the link quality by cooperation. When the destination fails to decode the data from the source, the relay retransmits it. The retransmission is not as usually done by the source, but by the relay node becoming a kind of proxy that can work in place of the source. This idea of proxy nodes has been recently introduced in the 802.16 standard [2], we introduce it at the IEEE 802.11 level.

Considering the proxy process, it is difficult to locate this process in the traditional layer modeling: it is a MAC (Medium Access Control) process based on IEEE 802.11 and a dynamical bridge process that uses a layer 2 routing table. This table is dynamic as it depends on the link quality. We propose a retransmission mechanism that is done either by the source or by the relay depending on the channel state information, this mechanism is cross layered. This type of layering has been intensively studied in the IEEE standards. The 802.11s drafts specify a layer 2 routing protocol with metrics for a multi-hop transmission [3]. This would be useful to the proxy transmission achievement. Thus, the proxy cooperative transmission is convenient for either 802.11 LAN or 802.11s WLAN Mesh Network based on IEEE 802.11s standard (WMN).

In order to set up a cooperative transmission among wireless nodes, several cooperative protocols have been proposed in literature [4-12]. Generally inspired from the IEEE 802.11 MAC standard, the activation and deactivation of the cooperative mode requires some extra control frames, and/or modifications of the control frame structure [13]. For example in [9], the source terminal S (see figure 1) requires help from neighbors through a relaying-start (RS) frame. Each potential relay (R<sub>i</sub>,...,R<sub>j</sub>) sends back a Relay Acknowledgment frame (RA). Upon the reception of these frames, terminal S selects the best relays from the associate power and notifies the selected relays by sending a relay-broadcasting (RB).

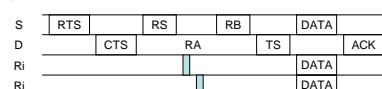


Figure 1. An example of on-demand cooperative systems.

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In this example, there are new frames and a new MAC frame scheduling that cause some interoperability problems with the legacy systems. The objective of our paper is to propose a method that is IEEE 802.11 compatible. Only some process modifications are required and affect only the nodes with cooperative functionality. In addition, our method does not use or modify request-to-send (RTS) or clear-to-send (CTS) frames; therefore, it can work compatibly with both of the basic and the optional access methods of the IEEE 802.11 MAC protocol.

Our proxy proposition intends to increase the link quality as a cooperative mechanism, and also to prevent unnecessary routing processes such as route maintenance and re-route discovery. In addition, the proposed method can avoid incorrect route selections. Incorrect route selections happen when an unnecessary multi-hop transmission is miss-chosen instead of a direct (1-hop) transmission, due to a route maintenance occurs when the link quality of the direct path is still dropped (deep fade), and causes performance degradations to the network. Comparing to direct transmission, a multi-hop one will increase transmission delays especially in IEEE 802.11 environment where more collisions can occur. Thus, to evaluate the interest of our proposition, the PDR and also the routing process invocation rate should be considered.

The rest of the paper is organized as follows. In section II, the proxy cooperative transmission principle is presented. In section III, the proxy cooperative process is described together with necessary modifications on the nodes with cooperative functionalities. Section IV is devoted to performance evaluations while Section V concerns with simulation results and analysis. The analysis of simulation results is based on PDR and on NRDM per second. Section VI illustrates the proposed method application. Finally, the conclusion is drawn in section VII.

## 2. PROXY COOPERATIVE TRANSMISSION PRINCIPLE

Our proposition is designed for a WiFi network using an IEEE 802.11 MAC protocol. For interoperability purposes, rather than specifying a new protocol, we decided to derive benefit from the handshaking access mechanisms to activate or deactivate the cooperative mode. Mechanisms of the non-cooperative and proxy-cooperative transmissions are shown in figure 2 with the basic access method (two-way handshaking; Data/ACK) and in figure 3 with the optional access method (four-way handshaking RTS/CTS/Data/ACK). Through this paper, S, R, and D stand for Source, Relay, and Destination respectively. R is assumed to be chosen and located in the transmission ranges of S and D.

Figure 2a and 3a represent message flows of non-cooperative systems with successful transmission. On the contrary, when D fails to decode a data frame, the timer expiration at the source S leads to data retransmission (figure 2b and 3b). For our proposed method, the successful data transmission process is unchanged (figure 2c). Changes appear only in case of failed transmissions, where R, on a per frame basis, can help S. More precisely, by hearing the ACK, R knows that the data frame has been successfully decoded at D; thus, R keeps quiet (the cooperative mode is automatically turned OFF; figure 2c and 3c). In this case, the message flow of the proposed method is similar to the non-cooperative system one. If D does not successfully decode the data frame (figure 2d and 3d), the absence of ACK reception

automatically turns ON the proxy cooperative mode at R. When the network allocation vector (NAV) of R reaches to zero, R forwards the data (without any changes in the header) to D. If D can decode the data sent from R, it replies an ACK back to S, and then S sends its next data frame. If not, S retransmits the data.

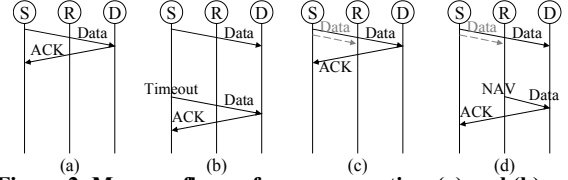


Figure 2. Message flows of non-cooperative, (a) and (b) cases, and proxy cooperative systems, (c) and (d) cases, working in a basic access method of the IEEE 802.11 MAC protocol.

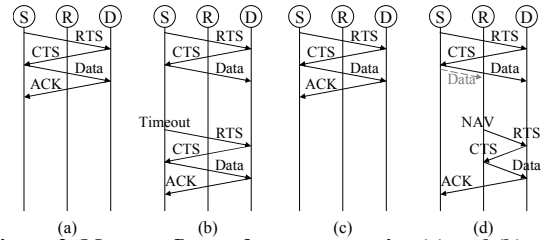


Figure 3. Message flows of non-cooperative (a) and (b) cases, and proxy cooperative systems, (c) and (d) cases, working in an optional access method of the IEEE 802.11 MAC protocol.

## 3. PROXY COOPERATIVE PROCESS

We detail here the proxy method achievement on the three terminals: Source (S), Relay (R), and Destination (D).

**S-extension :** in figure 3b and 3d, if S does not receive an ACK before its transmission timeout, the S re-transmission process is started. Meanwhile, the absence of ACK will lead R to retransmit the data. Thus, in order to avoid collision between S and R retransmissions, the value of the retransmission timer at S should be extended at least two times as usual to be able to cover an ACK caused by data received from R.

**R-extension :** we identify two processes to be extended.

**Data Filtering:** normally, nodes in a wireless communication listen to all the frames and filter them depending on the destination MAC address field value. If the address does not match a broadcast MAC address or the MAC address of the node, frames are deleted. But, in proxy mode, node R has to acquire MAC addresses of the transmission pair (S and D) that it has to help in order to filter and forward the data correctly. So, we added an additional table in MAC layer called a *proxy cooperative table*. Its content is fulfilled from the relay selection processes, which can be done by upper layers. Because of lack of place, details of the relay selection procedure will not be presented in the paper. For the rest of the paper, we consider that relays have been already chosen. We are currently working on this topic to fulfill the layer 2 table either through the level 3 routing protocol or through the level 2 routing protocol when it exits. The layer 3 AODV (Ad hoc On-Demand Distance Vector) routing protocol or the layer 2 HWMP (Hybrid Wireless Mesh Protocol) protocol are used in order to obtain channel state information (CSI) for relay selection. The first protocol is concerned in the WiFi network, while the second is related to the IEEE 802.11s WMN networks.

**Data Forwarding:** in the proposed method, D has to acknowledge the data directly to S even it receives the data from R. Therefore, R has to forward exactly the same data frame, received from S, to D. The relay has not to change anything on the header of the forwarded data frames. R acts as a dynamical bridge since forwarded data frames do not need to be sent up to the network layer. In addition, after forwarding the data, R does not need to wait for an ACK packet from D.

**D-extensions :** no modification is needed at the destination in the data receiving process.

#### 4. SYSTEM MODEL EVALUATION

We evaluate the performance of our proposed method by simulations and compare it with a non-cooperative transmission. NS 2.30 simulator is used [14]. The performance evaluation is done with two metrics 1) the transmission performance evaluated in terms of PDR [15] and 2) the administrative (routing) performance evaluated in terms of NRDM per second. For the routing protocol, the IETF AODV protocol is chosen [16]. In case of link failures, the routing protocol looks for a new route. NRDM is the number of route request (RREQ) packets that have been sent by S to look for new routes during the simulation.

In the evaluations, simple cell context as shown in figure 4 is used. There are no interferences from other terminals. R and D are in the coverage area of S. R is assumed to be already chosen, and it is located in the transmission range of S and D. The two ray ground propagation model is used for physical channels while IEEE 802.11, and AODV are used as MAC, and routing protocols. User Datagram Protocol (UDP) agents are created to send Constant Bit Rate (CBR) traffic with data rate 448kbps and packet size equal to 210 bytes. Simulation time is 100 seconds.

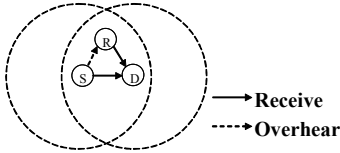


Figure 4. 3-node scenario.

Because the interest of the cooperative mode is connected to the link quality, we vary the error probability of the paths. A probability error to 0.1 and 0.15 per frame are set for the direct path (S to D), while the proxy paths (S to R and R to D) have their error probabilities varying from 0.05 to 0.3 per frame.

**Direct path error:** we chose probability error values 0.1 and 0.15 in order to generate two different scenarios during the simulation. The probability error equal to 0.1 causes the non-cooperative system to process unnecessary route maintenances only, while the probability error equal to 0.15 causes the non-cooperative system to process both of unnecessary route maintenances and to select an incorrect route. We consider that an incorrect route selection occurs when the routing protocol chooses the three-node route (S-R-D: multi-hop transmission) rather than the direct route (S-D: direct transmissions). When data are transmitted on the three-node route, the proxy mode is never used.

**Proxy path error:** variations of the probability error in proxy paths are set in order to study the performance of the proposed algorithm, when the link quality of the proxy path is better or worse than the direct path one.

#### 5. SIMULATION RESULT AND ANALYSIS

NRDM is presented on figures 5 and 6 while figures 7 and 8 present PDR of the system with and without proxy cooperations in different link quality configurations. The frame error probability of the direct link ( $P_1$ ) is set at 0.1 per frame in Figure 5 and 7, and it is set at 0.15 in figures 7 and 9. We vary the frame error probability of each proxy link ( $P_2$ ) in a proxy path from 0.05 to 0.3 per frame. The x-axis of figures 5 to 8 is plotted in terms of the ratio between  $P_1$  and  $P_2$  ( $P_1/P_2$ ) varying from 0.5 to 2.0.

As expected, figure 5 and 6 show that the value of the NRDM per second of the proposed technique is globally lower than that of the non-cooperative transmission because the link quality is increased. The proposed method can minimize the probability of data error at the destination when the link quality of the proxy path is better than the direct path one. Equation (1) and (2) respectively show the probabilities of correct data reception at D for the non-cooperative and proxy cooperative transmissions.

$$P_{correct}^{Direct} = 1 - P_1 \quad (1)$$

$$P_{correct}^{Proxy} = (1 - P_1) + P_1(1 - P_2)^2 \quad (2)$$

First term of eq. (2) is the probability that D can successfully decode the data frames sent by S. The second one is related to the probability that D can successfully decode the data frames sent by R, which is able to minimize the probability of data error at the D.

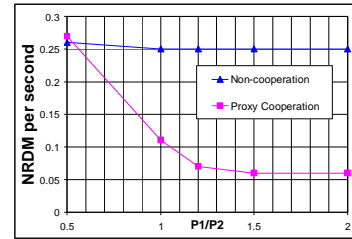


Figure 5. NRDM per second ( $P_1 = 0.1$ )

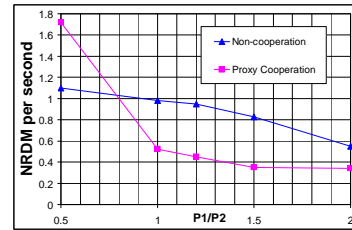


Figure 6. NRDM per second ( $P_1 = 0.15$ )

In figure 5 and 7 ( $P_1=0.1$ ), the values of NRDM and of PDR for the non-cooperative transmission are nearly constant because the error probability of the direct path is not large enough to switch the data transmission through the multi-hop path. Due to error transmissions, the routing protocol has to search a new route (it generates NRDM), but the direct path is restored because its link quality returns to have a good quality when the route maintenance occurs. Therefore, the performance of the system is only function of the link quality of the direct path. The increasing of  $P_1/P_2$  does not affect the performance. In contrast, the values of NRDM and PDR for the non-cooperative transmission in figure 6 and 8 ( $P_1=0.15$ ) are not constant. The system performance depends on the link qualities in both of the direct path and the proxy path.  $P_1$

is set at 0.15, which is large enough to make the system to switch its data transmission through the multi-hop path (S-R-D) since a route maintenance occurring when the link quality of the direct path is dropped. When the system chooses to transmit its data through the multi-hop path instead of the direct path, it generates what we called an incorrect route selection. Figure 9 shows that the number of data routed through the multi-hop path for non cooperative system is not very significant until  $P1/P2=1$ , and then it grows rapidly leading to some performance decreasing noted in figure 8. This lost of performance is due to the collisions. So, the reduction of PDR in non-cooperative transmissions is more severe when the link qualities of the proxy paths are increased. Note that, if the non-cooperative transmission can well transmit its data in the multi-hop transmission, there is no route maintenance. Thus, the system would less frequently switch back to send its data by the direct path again when  $P1/P2$  increases. It is why the NRDM decreases in figure 6, and the PDR decreases too in figure 8.

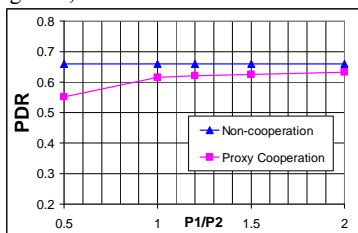


Figure 7. PDR (P1 = 0.1)

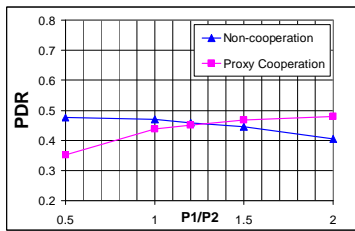


Figure 8. PDR (P1 = 0.15)

Concerning to the proxy method, in figure 5 and 6, its NRDM is high when the link quality of the proxy path is quite worst than the proxy path one. The channel imperfection causes R to miss-hear ACK packets. Therefore, R competes with S on sending the data. It also leads to some collisions in the handshaking method that conducts the routing layer to process route maintenances. Moreover, when the link qualities of the proxy path are worse than the direct path, the PDR of the proxy method is lower than those of the non-cooperative transmission because of two major reasons. Firstly, because of the collisions generated by R when it missed-hears ACK packets. Secondly, due to the extended retransmission time introduced by the inefficient relay transmission i.e. R should be activated to help S, but it is also unable to decode the data frame; thus, D has to wait for the retransmission done by S after the extended timeout, which is twice longer than the one of the non-cooperative technique, reaches to zero. The PDR of the proposed method functionally increases to the link qualities of the proxy paths since the relay can perform its proxy cooperative mode efficiently. Meanwhile, because the non cooperative network does not use the multi-hop transmission for  $P1=0.1$ , proxy method has no interest compared to the time consumed for proxy retransmission. On the contrary, when  $P1=0.15$ , non-cooperative network uses multi-hop transmission while proxy does not (see figure 9).

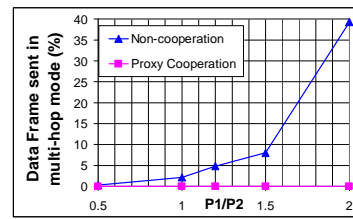


Figure 9. Data frames sent in multi-hop mode (P1 = 0.15)

Thus, the proposed technique is interesting as it provides a better PDR than the non-cooperative transmission when the link quality of the proxy path is better than the direct path and when the error condition leads to incorrect route selections.

## 6. PROXY COOPERATIVE TRANSMISSION IN IEEE 802.11S WLAN MESH NETWORKS

An example to implement proxy concept in WMNs (WLAN Mesh Networks) is presented. Rather than to interconnect wireless LAN by a wired Ethernet system and a level 3 interconnection, the objective of the 802.11s group is to achieve a level 2 interconnection by the wireless way in order to constitute a WMN. Bridging is done by a new routing protocol (basic IEEE 802.1D bridging routing are the transparent and the source routing ones) called Hybrid Wireless Mesh Protocol (HWMP). HWMP is a hybrid routing protocol having both of reactive and proactive routing components. The on-demand routing part is derived from the AODV protocol. Besides, some metrics related to the CSI are specified to the routing process. Thus, our proposition is usable to WiFi networks as well as to WiFi meshed networks.

The proxy cooperative concept application to the WMN architecture is illustrated in figure 10. The Mesh Point (MP) is an IEEE 802.11 station with mesh capabilities. The Mesh Access Point (MAP) is a MP having additionally access point functionality. STA (Station) is a conventional (or legacy) WLAN client, which is a non-mesh IEEE 802.11 station. A MP with additional portal function is called mesh portal (MPP). It can bridge data frames to other IEEE 802 networks.

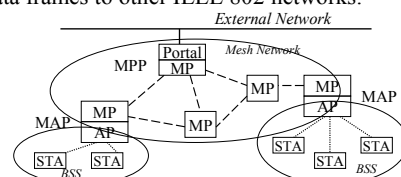


Figure 10. Network architecture of IEEE 802.11s WMNs

Proxy cooperative transmission can be applied into 2 places in WMNs. At the first, it can be applied to gain the signal diversity in Basic Service Set (BSS) as shown in Figure 11(a1 and a2). At the second, (see Figure 11(b)), it can be applied to gain the signal diversity at the MP level .

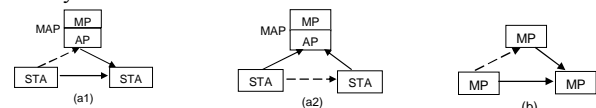


Figure 11. (a1) and (a2) Proxy cooperation in BSS, (b) Proxy cooperation in Mesh networks

In IEEE 802.11s draft, every mesh node is required to implement the default routing protocol HWMP. It allows each mesh node to create a MAC address table of its neighbor MP. So, cooperative

and proxy cooperative transmissions can be easily applied because the data forwarding in these transmission modes requires a pair of STA MAC addresses or a pair of MP MAC addresses to filter and forward the MAC data frames

## 7. CONCLUSION

In this paper, we have proposed a new cooperative transmission based on a proxy method that can work compatibly with the legacy systems and is compatible to both of the basic and the optional access methods of the IEEE 802.11 MAC protocol. It is also valuable for the 802.11s environment. We have simulated our proposition for a wireless mesh network. The performance has been considered not only in the MAC level but also in the network one with its routing process. From simulation results, it shows that the proposed method outperforms the non-cooperative transmissions in terms of transmission performance (evaluated by PDR) and in terms of routing performance (evaluated by NRDM per second), when non-cooperative transmissions face with incorrect route selection problems and a “good” relay is chosen to work in proxy cooperative mode. A “good” relay means a node locating in the transmission range of a source/destination and having the link qualities of its proxy paths (S-R and R-D) better than the direct path one (S-D). From simulation results, we propose to trigger the proxy mechanism function of the link qualities (S-D, S-R and R-D) that have been observed during the routing process by cross-layering. Thus, a node is configured with just an extended version of IEEE 802.11, where the extension is activated according to the network channel state information (CSI). If the CSI corresponds to a pattern where there is no multi-hop transmission, then the proxy mode has not to be used since it is more costly to retransmit by the relay than the source. However, even if the prevision of the CSI pattern is not accurate (the proxy mode is activated while there is no multi-hop transmission), it is not so serious because the cost increase is small.

In this work we have put forward the functioning of the proxy mode by fixing some error probabilities among three nodes. We are studying the performance of a system tacking account interferences issued from other nodes. Results in progress confirm the interest of the proxy mode according the CSI values. Next step is to model more closely the channel variation in order to precise the error probability. Besides, most of cooperative transmissions designed in MAC layers aims to improve the transmitting performances only for data frames. In fact, all the control frames of the access method (RTS, CTS, and ACK) are also adversely affected by the fading. Future work will allow the relay to cooperate on forwarding these control frames in order to improve the transmission performance of the system.

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