Cooperative strategies comparison for infrastructure and vehicle communications in CAPTIV

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***Abstract*—In wireless distributed networks where multiple antennas can not be installed in one wireless node, cooperative relay and cooperative Multi-Input Multi-Output (MIMO) techniques can be used to exploit the spatial and temporal diversity gain in order to reduce the energy consumption. The energy efficiency of cooperative MIMO and relay techniques is very useful for the medium to long distance transmission in Wireless Sensor Networks (WSN). The performance and the energy consumption of these two cooperative techniques are investigated in this paper in the context of Vehicle to Infrastructure and Infrastructure to Vehicle communications. The detailed comparison between relay and cooperative MIMO techniques in terms of performance and energy consumption shows that cooperative MIMO techniques have some advantages over relay techniques. But under certain conditions, the relay is better than cooperative MIMO techniques (e.g. in the presence of large transmission synchronization error). The comparison between these two cooperative techniques helps us to choose the optimal cooperative strategy in terms the energy consumption.**

I. Introduction

In wireless sensor networks where multi-antenna can not be integrated into a single sensor node due to size and cost constraints, some individual sensor nodes can cooperate at the transmission and the reception in order to deploy a cooperative Multi-Input Multi-Output (MIMO) transmission scheme [4], [8], [7]. Cooperative MIMO can exploit the diversity gain of space-time coding technique to increase the energy consumption efficiency. In [3] [9],it has been shown that cooperative MISO and MIMO systems are more energy-efficient than Single-Input Single-Output (SISO) and traditional multi-hop SISO systems for medium and long range transmission in wireless distributed sensor networks.

Relay techniques have been known as a simple and energy efficient technique to extend the transmission range due to their simplicity and their performance for wireless transmissions over fading channels [6], [12] and [5].

The two cooperative techniques are proposed for cooperative transmissions in CAPTIV[1], an Intelligent Transport Systems project in Brittany Region, France, in order to reduce the energy consumption of wireless sensor nodes (road infrastructures).

In this paper, the detailed comparison between relay and cooperative MIMO techniques in terms of performance and energy consumption shows that cooperative MIMO techniques have some advantages over relay techniques. But under certain conditions, the relay is better than cooperative MIMO techniques (e.g. in the presence of large transmission synchronization error). The comparison between this two cooperative technique help us to choose the optimal cooperative strategy in terms of energy consumption for CAPTIV.

The rest of the paper is organized as follows. CAPTIV project and some cooperative strategies for the energy consumption optimization are presented in Section II. The Section III proposes the performance comparison of cooperative MIMO and relay techniques. Finally, the energy consumption of both cooperative techniques are presented in Section IV and the conclusion is given in Section V.

II. Cooperative Transmission Schemes in CAPTIV project

A scientific coordination group devoted to Intelligent Transportation Systems, called GIS ITS Bretagne, has been set up in the Brittany region, to investigate this research area. One of its projects, CAPTIV, aims at using existing infrastructure, i.e. road signs but also every infrastructure along the road, to transmit information inside a wireless network including equipped vehicles, as illustrated by Fig.1. The first applications offered by CAPTIV are road signs anticipated displays (including dynamic situations as temporary works on the road) and arriving vehicle indications. In such a network, every kind of information can be transmitted, leading then to more advanced applications which integrate live data and feedback from a number of other sources, such as parking guidance and information systems, weather information, and so on.

In plenty of communication scenarios in ITS, the transmission between the infrastructure and the vehicles are usually from a medium to long distance and a direct transmission, if possible, would need too much transmission energy. A multi-hop routing technique can be used for such transmissions but it is not efficient enough in terms of energy consumption in many cases. Relay and cooperative MIMO techniques are the better strategies in terms of energy efficiency. Considering that the circle and the rectangle stand respectively for the road sign and the vehicle in the transport system, some cooperative transmission strategies, illustrated in the following figures, have been proposed for energy efficiency transmissions in CAPTIV.

[1]Cooperative strAtegies for low Power wireless Transmissions between Infrastructure and Vehicles

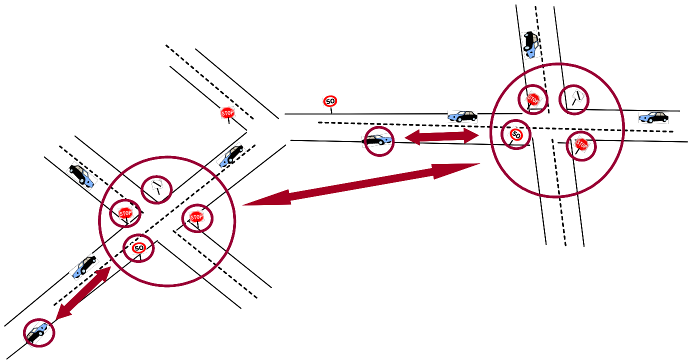

Fig. 1. Infrastructure-to-Infrastructure and Infrastructure-to-Vehicle wireless communications in the CAPTIV, Intelligent Transport System Project.

A. SISO multi-hop transmission in CAPTIV

The most simple cooperation scheme is the multi-hop SISO transmission like in Fig. 2. A message from a road sign (source node S) in one junction can be transmitted through multiple road signs (cooperation nodes) to a vehicle (destination node D).

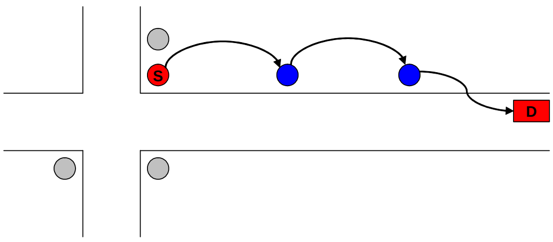

Fig. 2. Multi-hop SISO transmission between infrastructure and vehicle

B. Relay transmission in CAPTIV

In Fig.3, a message from the road sign can be transmitted to the vehicle (destination node D) and another road sign (relay node R). Then, the message is relayed from this relay road sign to the vehicle for signal combination. This technique is more energy efficient than multi-hop SISO for medium range transmission.

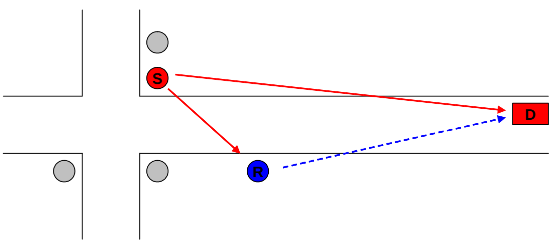

Fig. 3. Relay transmission between infrastructure and vehicle

C. Cooperative MIMO transmission in CAPTIV

Cooperative MIMO is an energy efficient cooperative technique for medium and long range transmission. Depending on the system topology (the available nodes) and the transmission distance, the optimal selection of transmit and receive nodes number can be chosen in order to minimize the total energy consumption.

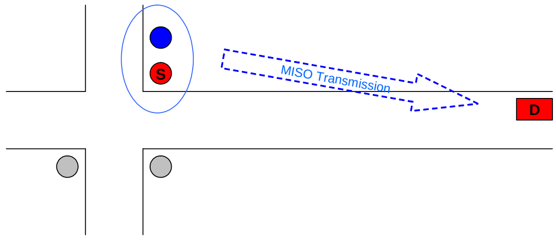

Fig. 4. Cooperative MISO transmission between infrastructure and vehicle

In Fig. 4, a road sign node S can cooperate with its neighbor road signs to employ a cooperative MISO (Multiple Input Single Output)technique to transmit a message to the vehicle (destination node D).

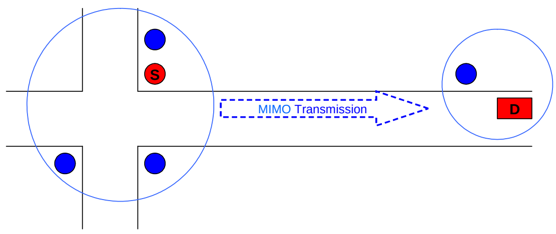

Fig. 5. Cooperative MIMO transmission between infrastructure and vehicle

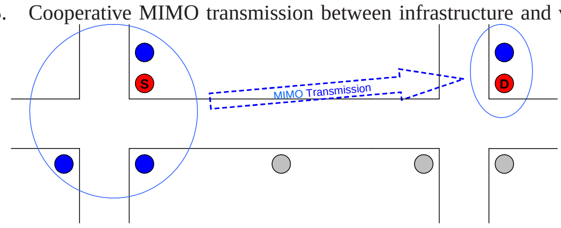

Fig. 6. Cooperative MIMO transmission between infrastructure and infrastructure

In Fig.5, the road sign node S and the vehicle node D can cooperate with their respective neighbor road signs to employ a cooperative MIMO transmission over a long distance. Another example of cooperative MIMO transmission in CAPTIV is shown in Fig. 6, where the road sign node S can cooperate with other road signs in one junction to transmit the message by using a cooperative MIMO technique to the cooperative reception road signs in the other junction.

D. Multi-hop cooperative MIMO transmission

For a long distance communication, the cooperative MIMO technique with the number of transmit and receive nodes greater than 2 has the energy consumption advantages [9], but this scenario can not be always employed because of the lack of available nodes. In this condition, a multi-hop technique using cooperative MIMO for each transmission hop is a suitable solution. For example, the communication between two crossroads with distance greater than 1km in Fig. 7, two road signs in the middle of the transmission line can be employed (and cooperate together) to perform a multi-hop cooperative MIMO transmission.

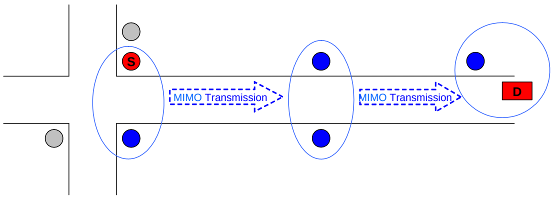

Fig. 7. Multi-hop cooperative MIMO transmission between infrastructure and vehicle

III. Cooperative MIMO and Relay Techniques Performance Comparison

The performance of relay techniques is limited by the decoding (or signal processing) process at the relay nodes. The error bit (or noise amplification) occurring at the relay node can not be always corrected at the destination node. Although with the same diversity gain, the performance of relay is always lower than MISO space time coding techniques.

Fig. 8 represents the Frame Error Rate (FER) performance comparison of the relay techniques (Amplify-and-Forward and Decode-and-Forward techniques) with the cooperative MISO technique for two transmit antennas. Due to the noise amplification or the error occurred at the relay node, the performance of Amplify-and-Forward and Decode-and-Forward relay techniques are $3dB$ and $4.5dB$ less than the cooperative MISO at the $FER = 10^{-3}$, respectively.

In parallel relay networks, the diversity gain increases with the number of independent fading received signals (i.e. the number of relay nodes). However, the performance of parallel relays also suffers from the noise amplification or the error bits that occurred at the multiple relay nodes. In Fig. 9, the performance comparison of parallel relay technique with two and three relay nodes using Decode-and-Forward technique with the cooperative MISO technique is shown. The source-relay distance $d_1 = d/3$ and the number of transmit nodes is three (i.e. two relay nodes, legend $Relay\ N = 3$) and four (i.e. three relay nodes, legend $Relay\ N = 4$). It can be observed that when the number of relay nodes increases, the performance increases. However, the performance gain is not as much as the cooperative MISO technique due to the error rate occurring at the relay nodes.

The performance of cooperative MISO technique is affected by the un-synchronized transmission of cooperative distributed networks [11] [10]. The advantage of relay techniques over cooperative MIMO techniques is that these techniques do not need the synchronous transmission of relay nodes, and so relay techniques do not suffer from the transmission synchronization error problem.

Fig. 10 shows the performance comparison of these two techniques with transmission synchronization errors range $\Delta T_{syn} = 0.25T_s$ and $0.5T_s$.

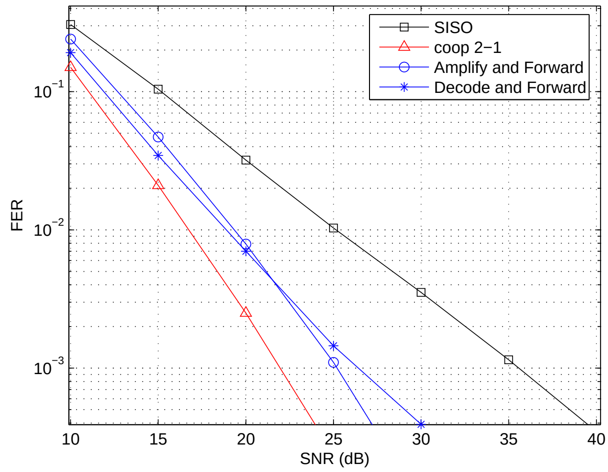

Fig. 8. FER of relay technique vs. cooperative MIMO technique with two transmission nodes, non-coded QPSK modulation over a Rayleigh channel, 120 bits/frame, source-relay distance $d_1 = d/3$, and power path-loss factor K=2.

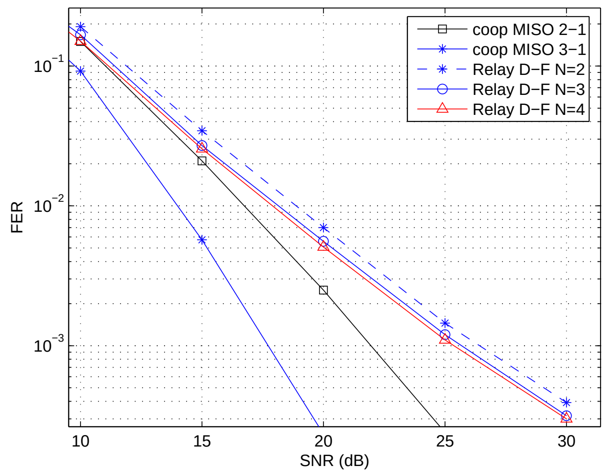

Fig. 9. FER performance of relay techniques vs. cooperative MIMO techniques with three and four transmission nodes, non-coded QPSK modulation over a Rayleigh channel, source-relay distance $d_1 = d/3$.

IV. Cooperative MIMO and Relay Techniques Energy Consumption Comparison

The energy consumption evaluation was performed using the system parameters presented in [2]. The detailed energy consumption calculation using this reference model can be consulted in [9]. The following figures represent the total energy consumption to transmit 10^7 bits with the error rate requirement $FER = 10^{-3}$ from a source node S to a destination node D separated by a distance d (over a Rayleigh quasi-static channel). The local distance between cooperative nodes in cooperative MISO techniques is $d_m = 5m$, the source-relay distance in relay techniques is $d_1 = d/3$.

It has been shown that the performance of the relay technique, with the same diversity gain order (i.e. same transmit

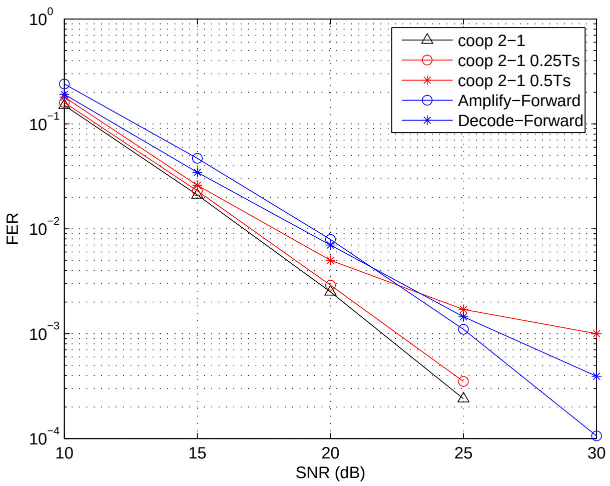

Fig. 10. Performance of relay technique vs. cooperative MIMO technique with transmission synchronization error $\Delta T_{syn} = 0.25T_s$ and $0.5T_s$, source-relay distance $d_1 = d/3$.

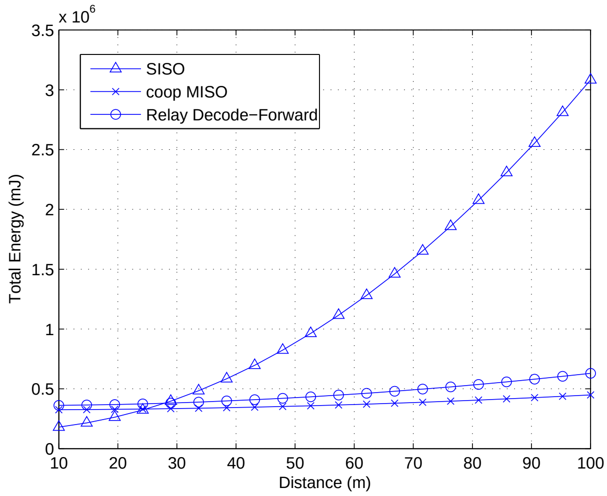

Fig. 11. Energy Consumption of relay technique vs. cooperative MIMO technique with two transmission nodes, power path-loss factor $K = 2$, source-relay distance $d_1 = d/3$.

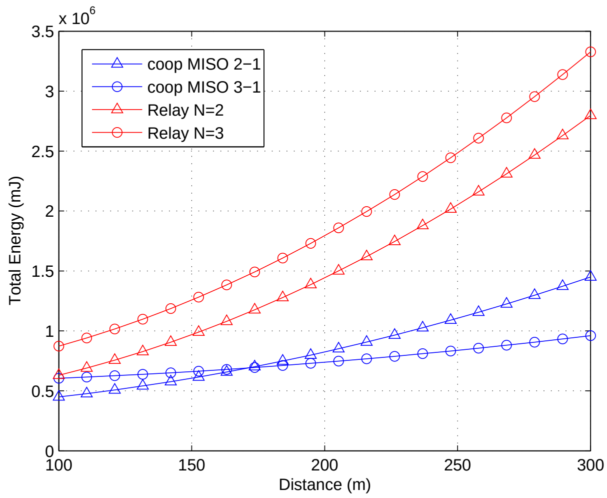

Fig. 12. Energy consumption of relay technique vs. cooperative MIMO technique with two and three transmission nodes, power path-loss factor $K = 2$, source-relay distance $d_1 = 1/3d$.

nodes number), is less than the MISO technique for the same received SNR. Otherwise, as the destination node must work in several time slots (N time slots), the circuit consumption of the relay technique will be higher than the corresponding cooperative MISO. Therefore, in many cases, the total energy consumption of the relay technique is higher than the cooperative MISO technique.

Fig. 11 shows the energy consumption of relay technique in comparison with SISO technique and cooperative MISO 2-1 technique (using MSOC technique in the presence of transmission synchronization error $\Delta T_{syn} = 0.25T_s$ [10]).

In Fig. 12, the energy consumption comparison of cooperative MISO and parallel relay techniques with a number of transmission nodes $N = 2$ and $N = 3$ is shown. It is obvious that the total energy consumption of cooperative MISO is smaller due to the fact that cooperative MISO needs less transmission energy (less required SNR) than parallel relay for the same error rate requirement.

A. Presence of transmission synchronization errors

In the presence of transmission synchronization errors, the performance of cooperative MISO technique decreases. Fig. 13 shows the energy consumption comparison of cooperative 2-1 and relay techniques with the path loss factor $K = 3$ and the transmission synchronization error $\Delta T_{syn} = 0.5T_s$. In this condition, the relay is clearly better than the cooperative MISO in terms of energy consumption.

B. Transmission Delay Comparison

For a parallel relay network with N transmit nodes, the system needs typically N transmission phases to transmit all signals from $N - 1$ relay nodes to the destination node (if orthogonal frequency channels are not considered). And for a cooperative MISO network with N transmit nodes, the system needs typically 2 transmission phases (data exchange and MISO transmission phases).

Due to the fact that high-speed transmission can be employed in the phase one of cooperative MISO (16-QAM modulation instead of QPSK modulation), the time needed of phase one is approximated as a half of the time needed of phase two for the case of $N = 2$, and less than a half for the case of $N = 3$ and $N = 4$.

Consider the time needed of one transmission phase of relay technique as a reference, Fig. 14 shows the delay comparison (number of needed phases) of cooperative MISO and relay techniques as a function of transmit node number ($N = 2, 3$ and 4).

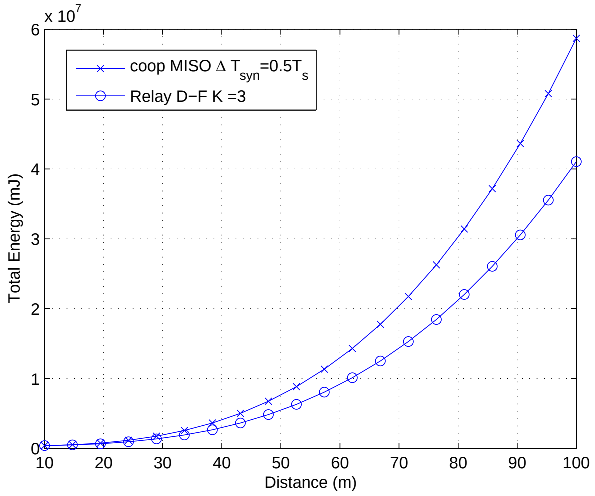

Fig. 13. Energy consumption of relay technique vs. cooperative MISO technique with two transmission nodes $N = 2$, power path-loss factor $K = 3$, error rate $FER = 10^{-2}$, transmission synchronization error range $\Delta T_{syn} = 0.5T_s$ and source-relay distance $d_1 = d/3$.

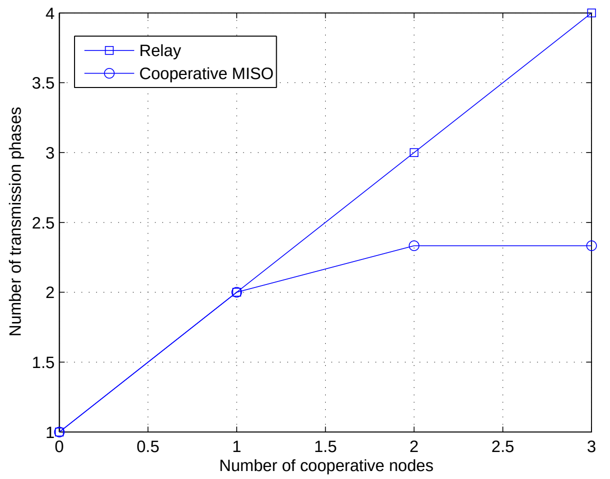

Fig. 14. Delay Comparison of Relay technique vs. Cooperative MISO technique with different number of cooperative (or relay) nodes.

V. Conclusion

Cooperative relay techniques provide attractive benefits for wireless distributed systems when the temporal and spatial diversity can be exploited to reduce the transmission energy consumption. Relay techniques are more efficient than the SISO technique, but still less efficient than cooperative MISO techniques in terms of energy consumption.

The performance of relay techniques is not as good as cooperative MISO techniques for the same SNR. However, relay techniques are not affected by the un-synchronized transmission scheme. When the transmission synchronization error becomes significant, the performance of relay is better than the performance of cooperative MISO, leading to a better energy efficiency.

The significant drawback of parallel relay techniques is the transmission delay of multiple relaying phases. In the simple scenario comparison of this paper, the transmission delay of cooperative MISO is obviously better than in the case of relay. However, the delay depends also on the higher layer protocols (e.g. MAC, LLC, Routing layer protocols). Therefore, taking account of the more complex protocols needed to deploy a cooperative MISO transmission [13], [1], the delay advantage of cooperative MISO may be smaller.

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