Green cooperative communication techniques for intelligent transportation systems

Vinod Kumar, Mogadala; Swaminathan, Ramabadran; Roy, Rajarshi

2013

Vinod Kumar, M., Swaminathan, R., & Roy, R. (2013). Green Cooperative Communication Techniques for Intelligent Transportation Systems. 2013 IEEE International Conference on Signal Processing, Computing and Control (ISPCC), 13898023-.

<https://hdl.handle.net/10356/81616>

<https://doi.org/10.1109/ISPCC.2013.6663432>

© 2013 IEEE. Personal use of this material is permitted. Permission from IEEE must be obtained for all other uses, in any current or future media, including reprinting/republishing this material for advertising or promotional purposes, creating new collective works, for resale or redistribution to servers or lists, or reuse of any copyrighted component of this work in other works. The published version is available at: [<https://doi.org/10.1109/ISPCC.2013.6663432>].

Downloaded on 26 Apr 2023 21:56:48 SGT

Green Cooperative Communication Techniques for Intelligent Transportation Systems

M Vinod Kumar

E & ECE Department
Indian Institute of Technology
Kharagpur, India
mogadala.vinod@gmail.com

Swaminathan R

E & ECE Department
Indian Institute of Technology
Kharagpur, India
swaminathan.ramabadr@gmail.com

Rajarshi Roy

E & ECE Department
Indian Institute of Technology
Kharagpur, India
royr@ece.iitkgp.ernet.in

Abstract—The current scenario of transportation infrastructure demands the need for developing efficient intelligent transportation systems (ITS) because of the increased population, changes in population density, traffic congestion, etc. Recent literature on ITS discuss on the need for green cooperative diversity techniques to improve the energy efficiency of the wireless nodes which are embedded in the transportation infrastructure. In the present work, we propose single-input-multiple-output (SIMO) and spatial modulation (SM) techniques for multiple antenna cooperative ITS in order to improve the energy efficiency of wireless nodes. Moreover, the symbol error probability (SEP) performance and energy efficiency of the proposed techniques are analyzed and compared with the traditional techniques. From the simulation results, it has been inferred that energy efficiency of cooperative ITS can be improved by employing SIMO technique, whereas both energy and spectral efficiency improvement can be obtained by employing SM technique.

Keywords— Cooperative ITS, Intelligent transportation systems, Single-input-multiple-output, Spatial modulation

I. INTRODUCTION

The increase in world population, changes in population density, urbanization, increased motorization, increase in travel time, air pollution, fuel consumption, etc. are the major factors playing a vital role in reducing the efficiency of transportation infrastructure. So in order to solve the existing transportation problems, intelligent transportation systems (ITS) technology is actively explored in the literature [1]. Various modern telecommunication techniques along with other current technologies are included in our existing transportation system to establish a real-time, accurate, and efficient ITS.

Since the wireless channels between the vehicles and transportation infrastructure deteriorate due to fading, recently cooperative diversity techniques have also been included in ITS to increase the system reliability as well as the coverage distance [2]-[3]. In cooperative ITS, vehicles communicate with each other and also with the transportation infrastructure to contribute positively towards the common goal of increasing the safety and efficiency of the transportation systems. Moreover as mentioned in [1], the various possible communication paths between the vehicle and infrastructure are vehicle-vehicle (V2V), vehicle-infrastructure (V2I), infrastructure-vehicle (I2V) and infrastructure-infrastructure (I2I). The communication among V2V, V2I, I2I, and I2V will be supported by wireless nodes, which should be energy efficient to increase the reliability and life time of the network.

Multiple-input-multiple-output (MIMO) techniques have been recognized as a key technology for modern wireless communication systems, which provide new degrees of freedom for improving the error performance and data rates compared to single antenna wireless systems as shown in [4]. Since there is a lack of literature work regarding the consideration of MIMO technology in cooperative ITS, in the present work we consider the same to improve the symbol error probability (SEP) performance, thereby making energy efficient ITS. The multiple receiving antennas at the relay and destination nodes provide diversity gain by receiving different versions of the same signal, since the probability of all the received signals to be in the deep fade condition at the multiple receiving antennas is very small.

The two general MIMO techniques which have been extensively studied in recent times for achieving the diversity and multiplexing gains are space time block code (STBC) and spatial multiplexing respectively. STBC technique provides a better way to exploit the spatial diversity gain because of its low implementation and decoding complexity as mentioned in [5]. However, it has been shown in [6] that constructing full-rate full-diversity code for more than two transmit antennas with linear complexity is impossible. Moreover, it has also been shown that higher data rates can be achieved via spatial multiplexing techniques such as V-BLAST (vertical bell laboratories layered space time) only at the cost of additional hardware and signal processing complexity and the complexity increases exponentially with the increase in the number of transmitting antennas. Therefore higher data rates and superior error performance are achieved at the expense of system complexity due to three primary reasons as mentioned in [6]. They are inter-channel interference (ICI), inter-antenna synchronization (IAS), and multiple radio frequency (RF) chains.

Spatial modulation (SM), a recently proposed MIMO transmission technique in [7], overcomes the above mentioned limitations in a novel approach. SM achieves high spectral efficiency and low complexity transceiver design without deteriorating the end-to-end system performance. In SM, the two dimensional plane is extended to three dimensional plane by incorporating a third dimension called spatial dimension. Symbols are transmitted from the selected antenna after being mapped through the traditional modulator. In SM, since part of the transmitted symbol information carries position of the transmitting antenna as an additional source of information, an improvement in spectral efficiency is achieved. Moreover in SM, during the given symbol transmission period just one transmitting antenna is active compared to conventional MIMO schemes, where multiple antennas are used to transmit data

streams simultaneously, thereby completely eliminating ICI and also does not require any antenna synchronization among the transmitting antennas. Further, in communication literature the concept of SM has been restricted to MIMO schemes and the application of SM scheme to cooperative relay techniques is lacking. So in our present work, energy and spectral efficient cooperative ITS have been developed by incorporating SM technique.

In [2], cooperative MIMO transmission scheme is proposed, where several nodes with single antenna cooperate with each other to improve the energy efficiency of ITS. In this paper, cooperative ITS with single-input-multiple-output (SIMO) and SM techniques are proposed for multiple receiving and transmitting antennas respectively. The proposed techniques are simulated by using Monte Carlo simulation method to observe the SEP performance and the energy consumption evaluation model proposed in [8] and [9] are used to determine the energy efficiency of our proposed system. From the simulation results it has been inferred that cooperative ITS with SIMO technique seems to be energy efficient compared to the single antenna cooperative ITS. However, cooperative ITS with SM technique seems to be both energy as well as spectral efficient compared to the existing techniques.

Rest of this paper is structured as follows; section II is about the system model, section III is about energy consumption evaluation model, which is used to determine the energy efficiency of our proposed techniques. Simulation results and discussions are given in section IV and finally, concluding remarks are given in section V.

II. SYSTEM MODEL

A. Cooperative ITS with SIMO technique

We consider a simple cooperative diversity scenario assuming no direct link between the source (S) and destination (D) nodes. A message from S can be transmitted to D with the help of intermediate relay node (R) as shown in the Fig.1. For instance, the source can be considered as a vehicle communicating with the transportation infrastructure, which can be considered as the destination node, with the help of another intermediate vehicle, which can be considered as the intermediate relay node.

In this technique multiple receiving antennas are considered at the relay and destination nodes. Moreover, single transmitting antenna is considered at the source and relay nodes. The complex baseband symbol received at the relay node antennas are modeled as

$$y_{srant1} = h_{srant1}S + n_{srant1}, \quad (1)$$

$$y_{srant2} = h_{srant2}S + n_{srant2}, \quad (2)$$

Fig.1. Dual hop transmission between infrastructure & vehicle

where s is the complex information-bearing baseband symbol which has energy E_s and belongs to M -ary phase-shift keying (MPSK) constellation S , which is given by

$$S = \{s_1, s_2, s_3 \dots s_M\},$$

where

$$s_m = \sqrt{2E_s} \exp\left(\frac{-j2\pi(m-1)}{M}\right), \quad m = 1 \dots M,$$

$$j = \sqrt{-1}.$$

The relay cooperates with the source through the DF relaying protocol. The relay node will detect the complex information-bearing baseband symbol using the following decision rule

$$\hat{S} = \arg \{ \max_{s \in S} \text{Re}(s^* h_{srant1}^* R_{srant1}) \}, \text{ if } \gamma_{srant1} > \gamma_{srant2}, \quad (3)$$

$$\hat{S} = \arg \{ \max_{s \in S} \text{Re}(s^* h_{srant2}^* R_{srant2}) \}, \text{ if } \gamma_{srant2} > \gamma_{srant1}, \quad (4)$$

where $(.)^*$ denotes the complex conjugate operation.

In the second time slot, the relay forwards the detected symbol $\hat{S}$ to the destination node. The complex baseband symbol received from the relay at the destination node is modeled as

$$y_{rdant1} = h_{rdant1} \hat{S} + n_{rdant1}, \quad (5)$$

$$y_{rdant2} = h_{rdant2} \hat{S} + n_{rdant2}, \quad (6)$$

where h_{srant1} , h_{srant2} , h_{rdant1} , and h_{rdant2} are the complex fading channel gains between source and two receiving antennas at the relay node and between relay and two receiving antennas at the destination node respectively. Similarly, n_{srant1} , n_{srant2} , n_{rdant1} , and n_{rdant2} are the additive white Gaussian noises of two receiving antennas at the relay and destination nodes respectively. Moreover, h_{srant1} , h_{srant2} , h_{rdant1} , and h_{rdant2} are modeled as independent zero-mean complex Gaussian random variables with unit variance. Further, n_{srant1} , n_{srant2} , n_{rdant1} , and n_{rdant2} are modeled as independent and identically distributed zero-mean complex Gaussian random variables with variance $2N_0$. Moreover, the norm of all the fading channel gains follow Rayleigh distribution and the Monte Carlo simulations have been performed over slow and flat Rayleigh fading channels. Further, we assume that the relay and destination nodes know the channel state information (CSI) of SR and RD links respectively.

Selection combining (SC) technique is used to combine the two received symbols at the destination node. The decision rule for combining the symbols at the destination node is as follows.

$$\hat{S} = \arg \{ \max_{s \in S} \text{Re}(s^* h_{rdant1}^* R_{rdant1}) \}, \text{ if } \gamma_{rdant1} > \gamma_{rdant2}, \quad (7)$$

$$\hat{S} = \arg \{ \max_{s \in S} \text{Re}(s^* h_{rdant2}^* R_{rdant2}) \}, \text{ if } \gamma_{rdant2} > \gamma_{rdant1}, \quad (8)$$

where γ_{srant1} , γ_{srant2} , γ_{rdant1} , γ_{rdant2} are the instantaneous signal-to-noise ratio (SNR) values of source to first and second receiving antennas at the relay node and relay to first and second receiving antennas at the destination node respectively.

B. Cooperative ITS with SM technique

In cooperative ITS with SM technique, multiple transmitting antennas are considered at the source and relay nodes. Based on the input bits at a given time instant only one transmit

antenna (i) is active. The symbol received at the relay node is modeled as

$$y_{sr} = h_{sr(i)}s + n_{sr(i)}, \quad i=1,2. \quad (9)$$

The relay node will detect the complex information-bearing baseband symbol using the SM detection principle. After detecting the symbol, the relay node will forward the symbol to the destination node. The symbol received at the destination node is modeled as

$$y_{rd} = h_{rd(i)}s + n_{rd(i)}, \quad i=1,2, \quad (10)$$

where $h_{sr(i)}$ and $h_{rd(i)}$ are the complex fading channel coefficients and $n_{sr(i)}$ and $n_{rd(i)}$ are the additive white Gaussian noises of respective SR and RD links. Moreover, $h_{sr(i)}$ and $h_{rd(i)}$ are modeled as independent zero-mean complex Gaussian random variables with unit variance. Further, $n_{sr(i)}$ and $n_{rd(i)}$ are modeled as independent and identically distributed zero-mean complex Gaussian random variables with variance $2N_0$. We assume that the relay and destination nodes know the CSI of SR and RD links.

SM conveys the information through the signal constellation and the antenna index number. So the detection part consists of transmit antenna index number estimation and the symbol estimation. The transmit antenna index number estimation is an important one in the detection process and if the estimation is wrong then it is not possible to recover the original information correctly. In the present work, the ML detection principle proposed in [10] is used for the detecting the received complex baseband symbol. In order to determine the transmit antenna index number and the transmitted symbol, the ML detection principle searches over all possible combinations of the transmitting antennas and the modulated symbols and finally selects the pair which gives minimum Euclidean distance (MED) from the received vector. ML detection principle can be described as follows

$$[t'', x_q''] = \arg \min_{t,q} \|y_t - h_t x_q\|, \quad (11)$$

where t'' is the estimated antenna index number, x_q'' is the estimated modulated symbol, y_t is the received symbol at the relay or destination node from the respective active antenna t , h_t is the fading channel coefficient of SR or RD link from the active antenna t , and x_q is the modulated symbol.

III. ENERGY CONSUMPTION EVALUATION MODEL

In order to determine the energy efficiency of the proposed techniques, the reference energy consumption evaluation model with the system parameters given in Table I is used [2]. The total power consumption for a conventional MIMO system consists of two components: i) transmission power of the power amplifier (P_{pa}) ii) circuit power of all the radio frequency blocks (P_c). The output transmission power (P_{tx}) decides the parameter P_{pa} and the output transmission power for a square law path loss channel as mentioned in [2] is given by

$$P_{tx} = \frac{\bar{E}_b R_b (4\pi d)^2 M_l N_f}{G_t G_r \lambda^2}, \quad (12)$$

Table 1

System parameters for the energy efficiency evaluation [2]

$f_c = 2.5\text{GHz}$	$\eta = 0.35$
$G_t G_r = 5\text{dBi}$	$N_0/2 = -174\text{dBm/Hz}$
$B = 1\text{MHz}$	$\alpha = 1.9$
$P_{mix} = 30.3\text{mw}$	$P_{syn} = 50\text{mw}$
$P_e = 10^{-3}$	$T_s = 1/B$
$P_{filr} = P_{filr} = 2.5\text{mw}$	$P_{LNA} = 20\text{mw}$
$N_f = 10\text{dB}$	$M_L = 40\text{dB}$

where $\bar{E}_b$ is the required mean energy per bit for achieving the given SEP, R_b is the bit rate, d is the transmission distance, G_t and G_r are the transmission and reception antenna gains, λ is the carrier wavelength, M_l is the link margin, N_f is the noise figure of the receiver, N_0 is the single side power spectral density (PSD) of thermal noise, M_n is the PSD of the total effective noise at the receiver input. The transmission power of the power amplifier (P_{pa}) as mentioned in [2] can be approximated as,

$$P_{pa} = (1 + \alpha)P_{tx}, \quad (13)$$

where $\alpha = (\zeta / \eta) - 1$, η is the drain efficiency of the RF power amplifier, and ζ is the peak-to-average ratio (PAR). From [2], the total circuit power consumption of N transmit and M receive antennas is given by

$$P_c \approx N (P_{DAC} + P_{mix} + P_{filr} + P_{syn}) + M (P_{LNA} + P_{mix} + P_{IFA} + P_{ADC} + P_{filr} + P_{syn}), \quad (14)$$

where N and M indicate the total transmitting antennas at the source and relay nodes and total receiving antennas at the relay and destination nodes respectively. Meanwhile, P_{DAC} , P_{mix} , P_{LNA} , P_{IFA} , P_{filr} , P_{filr} , P_{ADC} , and P_{syn} denote the power consumption values of the digital-to-analog convertor, the mixer, the low-noise amplifier, the intermediate-frequency amplifier, the active filter at the transmitter and the receiver, and the frequency synthesizer respectively. Since the power consumption of the baseband signal processing blocks such as source coding, pulse shaping and digital modulation are typically much smaller compared to the power consumption of RF blocks, the power consumption of the signal processing blocks are neglected in the energy consumption evaluation model.

The total energy consumption per bit (E_{bit}) for a conventional MIMO system as mentioned in [2] is given by

$$E_{bit} = (P_{pa} + P_c) / R_b \quad (15)$$

The energy consumption for a dual hop cooperative ITS considering single antenna case can be calculated by taking $N=2$ and $M=2$. Moreover, the energy consumption for cooperative ITS with SIMO technique is evaluated by determining the total number of transmitting and receiving antennas at the source, relay, and destination nodes. Meanwhile for cooperative ITS with SM technique, the total number of transmitting antenna is fixed as one, since only one RF chain is active between the source to relay node and relay to destination node.

IV. SIMULATION RESULTS AND DISCUSSIONS

Fig.2. Performance comparison of cooperative ITS with SIMO technique for dual hop scenario

Fig.3. Energy efficiency comparison of cooperative ITS with SIMO technique for dual hop scenario

From the figures MA denotes the multiple antennas and SER represents the symbol error rate. The Monte Carlo simulations for cooperative ITS with SIMO technique are carried out for binary phase-shift keying (BPSK) scheme with multiple receiving antennas at the relay or destination node or at both the nodes. Moreover, simulations are also performed by considering strong correlation as well as no correlation between the multiple antenna links. For the cooperative ITS with SM technique, multiple transmitting antennas are considered at the source or relay node or at both the nodes without correlation between the multiple antenna links and simulations are performed for quadrature phase-shift keying (QPSK) modulation scheme. The channel envelopes for correlated links are generated using Cholesky decomposition as given in [11].

A. Cooperative relay SIMO technique

From the Fig.2 and Fig.3, we can infer that when there is no direct link between the source and destination nodes, the SEP

Fig.4. Performance comparison of cooperative ITS with SM technique for dual hop scenario

Fig.5. Energy efficiency comparison for cooperative ITS with SM technique for dual hop scenario

performance and energy efficiency of cooperative ITS with SIMO technique can be improved compared to single antenna cooperative ITS [2] by considering multiple receiving antennas at the relay and destination nodes without correlation between the receiving antenna links. It has also been observed that though correlation exists between the receiving antennas at the relay and destination nodes, the SEP performance improvement as well as the energy efficiency improvement have been observed compared to the single antenna cooperative ITS technique. We can also infer that considering multiple antennas either at the relay or destination node alone cannot improve the SEP performance.

B. Cooperative relay SM technique

From the Fig.4, we can infer that the SEP performance improvement has been observed for cooperative ITS with single antenna source node considering QPSK modulation scheme and relay node with two transmitting antennas considering SM with BPSK modulation scheme compared to single antenna source and relay node with QPSK modulation scheme as proposed in [2]. Moreover, SEP performance improvement has not been observed by employing SM with BPSK modulation scheme considering two transmitting antennas at the source and relay nodes compared to single antenna cooperative ITS. Therefore to improve the performance of cooperative ITS, it is not necessary to employ SM at both the source and relay nodes.

From the Fig 5, we can also infer that only SM employed at the relay node has better energy efficiency compared to the single antenna cooperative ITS. Though cooperative ITS with SM techniques employed at both the source and relay nodes or only at the source node are not as energy efficient compared to the single antenna cooperative ITS, they are spectral efficient compared to the single antenna case, since the transmitting antenna also conveys the information to the receiver in SM technique. Finally, the energy efficiency using SM and SIMO techniques is achieved at the cost of installing multiple transmitting and receiving antennas at the wireless nodes compared to single antenna case.

C. Spectral efficiency of SM technique

In this sub section, the required number of RF chains and spectral efficiency of SM and V-BLAST techniques for single hop transmit diversity system is compared. For example, if we consider the number of transmitting antennas as 4 (i.e. $n_t = 4$) and QPSK modulation scheme ($M = 4$) then the spectral efficiency achieved by V-BLAST scheme is 8 bits per channel use (bpcu), whereas for SM it is 4 bpcu. In case of V-BLAST for achieving 8 bpcu, 4 RF chains are required and on an average with the help of one RF chain we can achieve 2 bpcu. But SM achieves 4 bpcu with single RF chain. Even though V-BLAST has high spectral efficiency, it requires more RF chains and the receiver decoding algorithm complexity also increases exponentially with the number of transmit antennas.

Table 2
Comparison of SM and V-BLAST

Technique	No of Antennas	No of RF chains required	Spectral efficiency (bpcu)
SM	2^m $m \in (1, 2, \dots)$	1	$m + \log_2^M$
V-BLAST	n_t	n_t	$n_t \log_2^M$

V. CONCLUSION

ITS play a vital role in improving the efficiency of existing transportation infrastructure. Wireless nodes are one of the important component in conveying the information between various elements of ITS. To improve the energy efficiency of wireless nodes employed in ITS, we proposed two energy efficient techniques for cooperative ITS, which are called green

cooperative communication techniques. In cooperative ITS with SIMO technique considering no direct link between the source and destination nodes, the SEP performance has been improved by considering multiple receiving antennas at the relay and destination nodes. Though correlation exists between the multiple antenna links, the SEP performance is better than the single antenna cooperative ITS technique. In case of cooperative ITS with SM technique considering no direct link between the source and destination nodes, the improvement in the SEP performance has been observed by employing SM only at the relay node. Moreover, it has also been observed that it is not necessary to employ SM at both the source and relay nodes for improving the energy efficiency. Though cooperative ITS with SM techniques employed at both the source and relay nodes or only at the source node are not as energy efficient compared to the single antenna cooperative ITS, they are spectral efficient compared to the single antenna case. Moreover, SM technique is less complex compared to MIMO scheme as only one RF chain is active at any given time instant.

Acknowledgement: Professor T. S. Lamba, former professor Dept. of E & ECE, IIT, Kharagpur who currently serves Jaypee University of IT as Dean, Academic and Research, suggested to the first author to work in ITS and the authors do thank him for his wise suggestion. The first author is supported by Govt. of India through a QIP scholarship and second author is supported by institute fellowship.

REFERENCES

- [1] S-h.An, B-H.Lee, and D-R.Shin, "A survey of intelligent transportation systems," in *the conference record of IEEE CICSyN*, pp. 332-337, July 2011.
- [2] T-D.Nguyen, O.Berder, and O.Sentieys, "Energy- efficient cooperative techniques for infrastructure-to-vehicle communications," *IEEE Transactions on Intelligent Transportation Systems*, vol.12, no.3, pp.659-668, September 2011.
- [3] T-D.Nguyen, Q-B V-Nguyen, M-T.Vo, and L.Mai, "Energy efficient cooperative communication techniques for intelligent transport system," in *the conference record of IEEE ATC*, pp. 76-80, August 2011.
- [4] J.Mietzner, R.Schober, L.Lampe, W.H.Gerstaecker, and P.A.Hoeher, "Multiple-antenna techniques for wireless communications – a comprehensive literature survey," *IEEE Communications Surveys & Tutorials*, vol.11, no.2, pp.87-105, Second Quarter 2009.
- [5] V.Tarokh, H.Jafarkhani, and A.R.Calderbank, "Space-time block coding for wireless communications: performance results," *IEEE Journal on Selected Areas in Communications*, vol.17, no.3, pp.451-460, March 1999.
- [6] M.D.Renzo, H.Haas, and P.M.Grant, "Spatial modulation for multiple-antenna wireless systems: a survey," *IEEE Communications Magazine*, vol.49, no.12, pp.182-191, December 2011.
- [7] R.Mesleh, H.Hass, C.W.Ahn, and S.Yun, "Spatial modulation – A new complexity spectral efficiency enhancing technique," in *the conference record of IEEE ChinaCom*, pp.1-5, October 2006.
- [8] S.Cui, A.J.Goldsmith, and A.Bahai, "Modulation optimization under energy constraints," in *the conference record of IEEE ICC*, vol.4, pp.2805-2811, May 2003.
- [9] K.Ntontin, M.D.Renzo, A.P-Neira, and C.Verikoukis, "Towards the performance and energy efficiency comparison of spatial modulation with conventional single-antenna transmission over generalized fading channels," in *the conference record of IEEE CAMAD*, pp.120-124, September 2012.
- [10] G.Mingxi, J.Chong, and S.Yuehong, "Detection algorithm for spatial modulation system under unconstrained channel," in *the conference record of IEEE ICCT*, pp.458-461, November 2010.
- [11] B.Natarajan, C.R.Nassar, and V.Chandrasekhar, "Generation of correlated Rayleigh fading envelopes for spread spectrum applications," *IEEE Communications Letters*, vol.4, no.1, pp.9-11, January 2000.