Paper

EARPC – Energy Aware Routing Protocol for Cooperative MIMO Scheme in WSNs

Kummathi Chenna Reddy[1], Geetha D. Devanagavi[2], and Thippeswamy M. N.[3]

[1] *Department of Electronics and Communication, Brindavan College of Engineering, Bangalore, India*
[2] *School of Electronics and Communication, REVA University, Bangalore, India*
[3] *Department of Computer Science, Nitte Meenakshi Institute of Technology, Bangalore, India*

https://doi.org/10.26636/jtit.2020.142720

Abstract—Wireless sensor networks are typically operated on batteries. Therefore, in order to prolong network lifetime, an energy efficient routing algorithm is required. In this paper, an energy-aware routing protocol for the co-operative MIMO scheme in WSNs (EARPC) is presented. It is based on an improved cluster head selection method that considers the remaining energy level of a node and recent energy consumption of all nodes. This means that sensor nodes with lower energy levels are less likely to be chosen as cluster heads. Next, based on the cooperative node selection in each cluster, a virtual MIMO array is created, reducing uneven distribution of clusters. Simulation results show that the proposed routing protocol may reduce energy consumption and improve network lifetime compared with the LEACH protocol.

Keywords—cluster head, cooperative MIMO, virtual MIMO, wireless sensor networks.

1. Introduction

One of the major concerns affecting WSNs is to minimize energy consumption for a single end-to-end transmission and to improve network lifetime. Over the years, various techniques have been proposed to improve energy efficiency in the energy-constrained environment. Among these approaches, multi-input and multi-output (MIMO) techniques, using more than one antenna, may be considered an effective solution for energy saving in WSNs. By considering various space-time coding scenarios and architectures, the MIMO approach is capable of improving channel capacity and of further reducing energy consumption [1]–[4]. However, multiple antennas cannot be connected to a single transmitter, and the antenna array cannot be accommodated in a sensor node due to the fixed frequency range.

In this paper, the location of sensor nodes and the remaining energy of nodes are considered while selecting cluster heads, and co-operative nodes are chosen for the MIMO system. This scheme may efficiently balance the load condition of the network and further enhance its lifetime.

In this paper, we propose an energy-aware routing protocol for cooperative MIMO scheme (EARPC), which addresses three limitations of the well-known low-energy adaptive clustering hierarchy (LEACH) protocol [5]. In LEACH, the selection of cluster heads is performed in the same manner for all nodes. Any node may become a cluster head, regardless of its remaining energy level. To enhance network lifetime, a novel cluster head selection technique that balances energy consumption based on the remaining energy of a node and on recent consumption of energy for all nodes is proposed. This scheme may further reduce the chance of low energy sensor nodes becoming cluster heads. In addition, co-operative nodes are chosen to form a virtual MIMO paradigm, based on the nodes' residual energy. Lastly, we propose an energy consumption model which aims to estimate the amount of energy required for collecting data among the nodes, for aggregating data at the CH level, as well as for intra and inter-cluster communication in the MIMO scheme.

This paper is organized as follows. Section 2 discusses the related work. In Section 3, the EARPC model is described. The energy consumption model is presented in Section 4. In Section 5, results of simulation parameters are presented and discussed. Finally, the paper is summarized in Section 6.

2. Related Work

To achieve energy-efficient cooperative MIMO networks, Cui *et al.* proposed, in [6], an energy efficiency and delay metric performance parameter for virtual MIMO approach for a single-hop system, which reduces energy consumption and delay for a given transmission range. In paper [7] Maadani *et al.* showed an adaptive data rate space-time coding (STC) technique. It is introduced for IEEE 802.11-based soft-real-time WSNs in which an enhanced distributed channel access (EDCA) is used at the medium access control (MAC) layer and MIMO transceivers are used at the PHY layer for minimizing average packet delay. Jayaweera *et al.* [8] proved that a precise model for energy consumption and cooperative MIMO technology may be considered as energy-saving for extra overhead. Sathian *et al.* in [9] proposed a trustworthy energy-efficient MIMO (TEEM) routing algorithm for WSNs, reducing energy consumption and enhancing the lifetime of a sensor network. The game theory is also used therein to select cluster heads based on the remaining energy of a node and on the trust level during the cluster head selection process.

Zuo *et al.* [10] proposed a BLAST code based on V-layered space-time for the cooperative communication scheme. This scheme achieves high energy efficiency and does not require any data exchange processes. Cooperative communication and data fusion approaches may further reduce energy consumption by removing data redundancy between sensor nodes [11]. Reddy *et al.* proposed, in [12], a QoS-oriented and energy-efficient routing protocol for cooperative MIMO-based mobile WSN: Q-E2RPC. In this scheme, a single mobile sink is used to reduce energy consumption. Li *et al.* proposed an energy-efficient cooperative MIMO scheme in [13], which combines the energy-efficient LEACH protocol and cooperative MIMO. In this protocol, the location of sensor nodes and the remaining energy of the node are considered while selecting cluster heads, and cooperative nodes are chosen for the MIMO system. This scheme may efficiently balance the load condition of the network and further enhance network lifetime.

3. System Model

Let us consider a real-time scenario in which a large number of sensor nodes is installed across the field. N clusters are formed by dividing the total number of sensor nodes, for collection and transmission of data in each round. Based on this assumption, we define the system model as follows:

- all sensor nodes collect data in the sensing area and transmit the collected data to the cluster head node,
- data aggregation may be performed at the cluster head level, which may save the transmitting energy by removing redundant data. Then, CH nodes forward their data to co-operative nodes,
- finally, co-operative nodes may form a virtual MIMO antenna array and forward their data to the sink node using multi-hop communication. An illustration of data transmission is shown in Fig. 1.

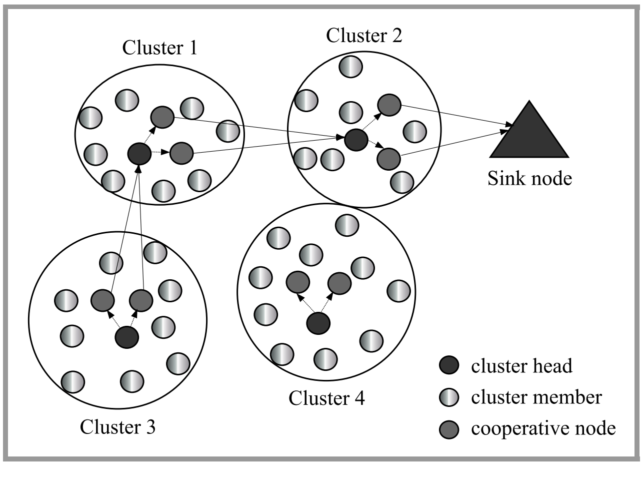

Fig. 1. Schematic representation of data transmission.

The main limitation of the LEACH protocol is that the cluster head selection probability is the same for all sensor nodes. Since the sensor nodes will have different energy levels and consumption rates, if nodes with low remaining energy or faster energy consumption are selected as cluster heads, then CH will stop functioning quickly and will disrupt communication between other nodes in that cluster and the CH. Network lifetime is also reduced if sensor nodes fail early.

To overcome the above-mentioned drawbacks, in this algorithm, the probability of a node becoming a cluster head is based on the ratio of remaining energy of the i-th node to the recent energy consumption of all nodes.

$$P(i)=\left\{\begin{matrix} \dfrac{n}{N-n\left[r \bmod \left(\frac{N}{n}\right)\right]}\cdot\dfrac{E_{rem}(i)}{E_{a_{rem}}}\cdot\dfrac{E_{a_{cons}}}{E_{cons}(i)} & \text{if } \ i\in G \\ 0 & \text{otherwise}\end{matrix}\right\}. \tag{1}$$

In Eq. (1) $E_{rem}(i)$ describes the remaining energy of i-th node and $E_{a_{rem}}$ refers to average remaining energy of the network. The other parameter $_{(a_{cons}}$ represents average energy consumption of the last round of transmission in the whole network and $E_{cons}(i)$ defines energy consumption of the i-th node.

The second limitation of the LEACH protocol is that the selection of cluster heads is random and the node selected may not be suitable (in terms of energy savings) for sending the collected data to the sink node. To overcome this, a cooperative MIMO routing algorithm is proposed.

After the formation the clusters, a few nodes may be chosen as co-operative nodes to form a virtual MIMO array. Here, the residual energy and distance are taken as important reference points for the selection of co-operative nodes [14]. The co- operative node selection threshold may be obtained from:

$$\delta = \frac{E_{rem}(i)}{d_i}\ , \tag{2}$$

where $d_{\min} \leq d_i \leq d_{\max}$.

In Eq. (2), $E_{rem}(i)$ refers to remaining energy of i-th node and d_i signifies distance between the cluster head and co-operative nodes, while $d_{\min}$ and $d_{\max}$ refer to minimum and maximum distance, respectively. The cluster head node is responsible for the selection of co-operative nodes with the highest threshold of δ, from all the participating nodes.

After co-operative nodes have been identified by the cluster head node based on the above criteria, the cluster head node will send a message to all cooperative nodes requesting their responsibility in virtual MIMO communication. This message contains the ID of co-operative nodes and TDMA schedules are assigned to all nodes.

Figure 1 shows a virtual MIMO data transmission in WSNs. Initially, the cluster head node broadcasts its message to collect data from its members. All sensor nodes forward their sensed data to the corresponding cluster head node based on their preassigned schedule slots. Then, sensor nodes will go to sleep mode to save energy. Next, cluster head nodes will perform data aggregation to reduce data redundancy (if any). Later, cluster head nodes forward their data to their cooperative nodes in their cluster. This phase is known as intra-cluster communication. finally, after receiving data from cluster heads, the co-operative nodes will form a virtual MIMO to perform a space-time block code. According to the routing table, the nodes transmit their data to the sink node using multi-hop transmission. This process is called inter-cluster communication.

4. Energy Consumption Model

In this section, we propose a model depicting energy consumption during intra- and inter-cluster communication in the network.

4.1. Energy Consumption Between the Nodes

The amount of energy consumed depends primarily on energy consumption of the transmitter and the receiver [2], [15]. Power consumption P_c may be expressed by:

$$P_c = M_t P_{ct} + M_r P_{cr} \ , \tag{3}$$

where:

$$\left.\begin{aligned} P_{ct} &= P_{DAC} + P_{mix} + P_{filt} + P_{syn} \\ P_{cr} &= P_{LNA} + P_{mix} + P_{IFA} + P_{filr} + P_{ADC} + P_{syn} \end{aligned}\right\} . \tag{4}$$

In Eq. (3), M_t and M_r represent the total number of transmitting and receiving nodes, and P_{ct} and P_{cr} refer to circuit power consumption of the transmitter's and receiver's circuits. In Eq. (4) P_{DAC}, P_{mix}, P_{filt}, P_{syn}, P_{LNA}, P_{IFA}, and P_{ADC} represent power consumption values of digital to the analog converter (DAC), mixer circuit, filter, frequency synthesizer, low noise amplifier, intermediate frequency, and analog to digital converter (ADC).
The power consumption of power amplifiers P_{pa} [16] is:

$$P_{pa} = (1+\alpha)\frac{(4\pi)^2 d^\beta M_l N_f}{G_t G_r \lambda^2} \times \overline{E_b} R_b \ . \tag{5}$$

In Eq. (5), α represents the power factor of the amplifier, d refers to the average distance between the cluster head and cluster members, M_l and N_f define link margin and receiver noise, λ is carrier signal wavelength, while $G_t G_r$ represent the gain of transmitting and receiving antennas. β is the path loss slope, $\overline{E_b}$ denotes energy consumption required by the receiver (i.e. sink node) to capture each bit of data under certain bit error rate (BER) conditions, and R_b denotes the data transmission rate under MQAM ($R_b = bB$ when the modulation order $b > 2$). The energy required to transmit and receive (per bit) between the nodes is given by:

$$E_{btr}(d) = \frac{P_{pa} + P_c}{R_b} = \frac{P_{pa} + M_t P_{ct} + M_r P_{cr}}{R_b} \ . \tag{6}$$

4.2. Energy Consumption Model within Cluster

Local intra-cluster communication is based on BPSK modulation and uses a single antenna (SISO) for transmission. Let P_b be denoted as BER) [17], [18]. Then, the average energy required to receive a bit correctly is:

$$\overline{E_B^{SI}} = \frac{N_0}{\left(1 - 2\overline{P_b}\right)^{-2} - 1} \ , \tag{7}$$

where $\overline{E_B}$ in Eq. (5) and *SI* refer to a single transmitting antenna. With $M_t = 1$ and BPSK modulation ($b = 1$), energy consumed for intra-cluster communication of 1 bit is:

$$E_{btr}^{SI}(d) = E_{btr}(d)\big|_{M_t=1 \text{ and } \overline{E_b}=\overline{E_b^{SI}}} \ . \tag{8}$$

Within each period, every sensor collects k-bits of data and sends that information to the corresponding cluster head. The total number of sensor nodes n_i of cluster i is ($i = 1, 2, \ldots, n$), where $d_{toCH}(i, j)$ represents the distance between the cluster head and intra node. Data collection-related energy consumption may be expressed as [17]:

$$E_{col}(i) = L \sum_{j=1}^{N_i-1} E_{btr}^{SI}\left[d_{toCH}(i, j)\right]\Big|_{M_r=1} \ . \tag{9}$$

In each transmission round, the cluster head will receive $L(n_i - 1)$ bits of data of i-th cluster. Assuming that E_{da} represents data aggregation-related energy consumption (on a per bit basis), energy consumption related to data aggregation may be given by:

$$E_{agg}(i) = E_{da} L(n_i - 1) \ . \tag{10}$$

The length of data after data aggregation, for cluster head, is:

$$L_f(i) = \frac{L(n_i - 1)}{f_{aff}(n_i - 1) - f_{agg} + 1} \ , \tag{11}$$

where $f_{agg} \in (0, 1)$ is the data aggregation factor [18].

4.3. Energy Consumption for Intra-cluster Communication

After performing data aggregation, the cluster head node broadcasts $L_f(i)$ bits of data to co-operative nodes N_C. To ensure that all sensor nodes in a cluster receive the data correctly, it defines the maximum distance between the cluster head and co-operative nodes by:

$$d_{toCN}(i) = \max\left\{d_{toCH}(i, j) \middle| j \in S_{coop}(i)\right\} \ . \tag{12}$$

In Eq. (12), $S_{coop}(i)$ represents a set of cooperative nodes. Intra-cluster energy consumption may be expressed as [17]:

$$E_{broadcast}(i) = L(i) E_{btr}^{SI}\left[d_{toCN}(i)\right]\Big|_{M_r=N_c} \ . \tag{13}$$

4.4. Energy Consumption for Inter-cluster Communication

During inter-cluster communication, the MIMO technique is used. When BER is less than $\overline{P_b}$, the required energy per bit $\overline{E_b^{MI}}$ is:

$$\overline{E_b^{MI}} = \frac{2}{3}\left(\frac{\overline{P_b}}{4}\right)^{\frac{1}{M_t}} \cdot \frac{2^b - 1}{\frac{1}{b^{M_t+1}}} \cdot M_t M_0 \ , \tag{14}$$

where *MI* denotes multiple inputs i.e. multiple transmitting antennas. Then, the required energy consumption of cooperative nodes communicating between different clusters is [18], [19]:

$$E_{btr}^{MI}(d) = \frac{R_b^{eff}}{R_b}\left[E_{btr}(d)|_{\overline{E_b}=\overline{E_b^{MI}}}\right] \ , \tag{15}$$

where $R_{b_{eff}}$ is the effective bit rate of the system [17]–[19]:

$$R_b^{eff} = \frac{F - pM_t}{F} RR_b \ , \tag{16}$$

where F is the block size of space-time block code (STBC), p denotes the number of symbols used to train each transmitting and receiving antenna pair, and R denotes the STBC coding rate.

Assuming that cluster i transmits the data h_i ($h_i \geq 1$) times to reach the sink node, the energy consumption of such a multi-hop transmission is:

$$\begin{aligned} E_{mulohop}(i) = L_f(i)\Big[E_{btr}^{MI}\left[d_{hop}(i,h_i)\right]\big|_{M_t=N_c,\, M_r=1} \\ + \sum_{k=1}^{h_i-1} E_{btr}^{MI}\left[d_{hop}(i,k)\right]\big|_{M_t=M_r+N_c}\Big] \ . \end{aligned} \tag{17}$$

In Eq. (17), $d_{hop}(i,k)$ denotes the distance of each hop ($i = 1, \ldots, h_i$) and E_{btr}^{MI} originates from Eq. (15).

Finally, the total energy consumption model E_{tot} may be expressed using Eqs. (9), (10), (13) and (17) is:

$$E_{tot} = \sum_{i=1}^{n}\left[E_{col}(i) + E_{agg}(i) + E_{broadcast}(i) + E_{mulhop}(i)\right] \ . \tag{18}$$

5. Results and Discussion

This section discusses primarily the experimental set and the results obtained. The performance of EARPC has been evaluated in Matlab, using the existing system, i.e. the LEACH protocol [5], in terms of average residual energy and network lifetime. The network parameters considered for the network model are shown in Table 1. During the simulation, 100 nodes were randomly distributed throughout the area of 100 × 100 m area as shown in Fig. 2.

Figure 3 shows the results of average residual energy simulations for both LEACH and EARPC protocols. The residual energy in the LEACH protocol depletes faster than in EARPC.

Figure 4 shows the number of nodes that are alive in each round, for both algorithms considered. Simulation results show that the node survival rate of the proposed protocol is higher than in the case of LEACH. It may be seen from Fig. 4 that the difference starts to become apparent at 1000 rounds, as the number of rounds increases with respect to the number of nodes. At $r = 1500$ rounds, the survival rate of the LEACH protocol is about 5 and in the case of the proposed protocol it equals approximately 95. So, it is clearly shown that the proposed EARPC protocol is more effective in terms of reducing energy consumption.

Figure 5 presents network lifetime for both LEACH and EARPC protocols. In LEACH, the first node is dead at round 1000, while in EARPC it is at 1550. Similarly, when

Table 1
Parameters using in simulation

Parameters	Value
Network area	100 × 100 m
Total number of sensor nodes N	100
Initial energy of network $E0$	50 J
Packet size L	2000 bits
Energy dissipation in power amplifier E_{amp}	100/pJ/bit/m^2
Energy dissipation during aggregation E_{DA}	20 nJ/bit
Energy dissipation in electronics E_{elec}	50 nJ/bit
Minimum distance $d_{\min}$	1 m
Maximum distance $d_{\max}$	50 m
Gain of transmitting and receiving antenna G_r	5 dBi
Power factor of an amplifier α	0.47
Carrier wavelength λ	0.12 m
Noise coefficient of the receiver N_f	10 dB
Channel bandwidth B	10 kHz
Aggregation factor f_{agg}	0.7
Power of the low-noise amplifier P_{LNA}	20 mW
Power of the frequency synthesizer P_{syn}	50 mw
Power of the mixer P_{mix}	30 mW
Power of transmitting circuit filter P_{filt}	2.5 mW
Power of receiving circuit filter P_{filr}	2.5 mW
Power of analog to digital converter P_{ADC}	10 mW
Power of digital to analog converter P_{DAC}	10 mW
Power of intermediate frequency amplifier P_{IFA}	20 mW
Set of symbols F	200
Bit error rate $\overline{P_b}$	10^{-3}

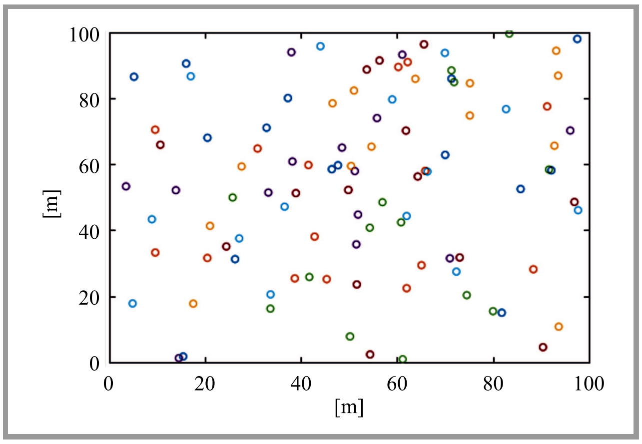

Fig. 2. Distribution of sensor nodes in network area.

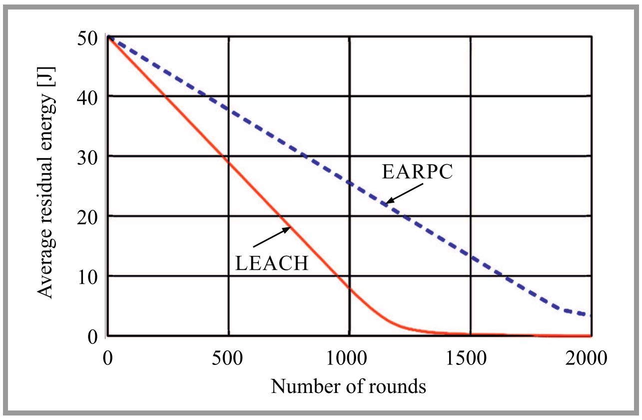

Fig. 3. Average residual energy of sensor nodes.

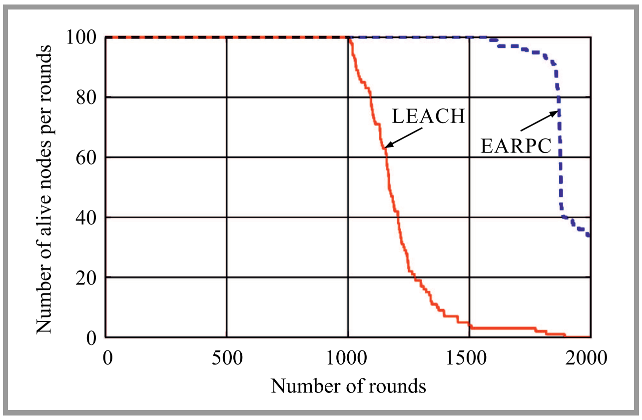

Fig. 4. Total number of alive nodes per round.

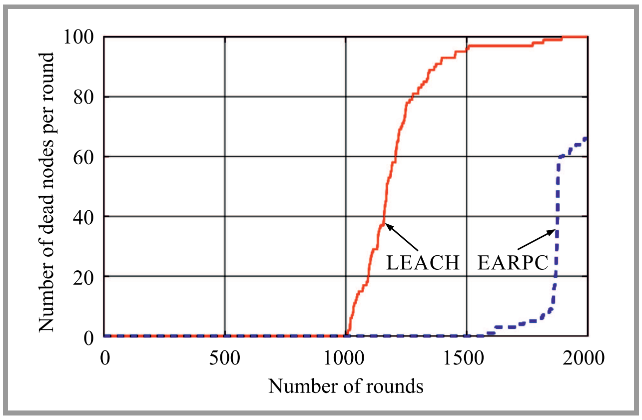

Fig. 5. Number of dead nodes per round.

$r = 2000$, the share of dead nodes is 100% in LEACH, whereas in EAPRPC, it is about 65%. As proven by the results, the proposed protocol reduces the death rate by 35% compared with the conventional LEACH protocol.

6. Summary

The proposed energy consumption model offers better performance in terms of energy consumption in WSNs. The new CH selection technique used balances energy consumption for different sensor nodes in a given cluster. The cooperative MIMO scheme further reduces uneven CH distributions. Therefore, with the overall performance taken into consideration, the proposed routing protocol is capable of reducing energy consumption and improving network lifetime.

References

[1] J. M. Chung, J. Kim, and D. Han, "Multihop hybrid virtual MIMO scheme for wireless sensor networks", *IEEE Tran. on Veh. Technol.*, vol. 61, no. 9, pp. 4069–4078, 2012 (DOI: 10.1109/TVT.2012.2213620).

[2] S. Cui, A. J. Goldsmith, and A. Bahai, "Energy-efficiency of MIMO and cooperative MIMO techniques in sensor networks", *IEEE J. on Selec. Areas in Commun.*, vol. 22, no. 6, pp. 1089–1098, 2004 (DOI: 10.1109/JSAC.2004.830916).

[3] L. Fei, Q. Gao, J. Zhang, and G. Wang, "Energy saving in cluster-based wireless sensor networks through cooperative MIMO with idle-node participation", *J. of Commun. and Netw.*, vol. 12, no. 3, pp. 231–239, 2010 (DOI: 10.1109/JCN.2010.6388451).

[4] P. Wang, and X. Zhang, "Energy-efficient relay selection for QoS provisioning in MIMO-based underwater acoustic cooperative wireless sensor networks", in *Proc. 47th Ann. Conf. on Inform. Sci. and Sys. CISS 2013*, Baltimore, MD, USA, 2013, pp. 1–6 (DOI: 10.1109/CISS.2013.6552272).

[5] W. R. Heinzelman, A. Chandrakasan, and H. Balakrishnan, "Energy-efficient communication protocol for wireless microsensor networks", in *Proc. of the 33rd Ann. Hawaii Int. Conf. on Syst. Sci.*, Maui, HI, USA, 2000 (DOI: 10.1109/HICSS.2000.926982).

[6] S. Cui, and A. J. Goldsmith, "Energy efficient routing based on cooperative MIMO techniques", in *Proc. IEEE Int. Conf. on Acoust., Speech, and Sig. Process. ICASSP'05*, Philadelphia, PA, USA, 2005, vol. 5, pp. 805–808 (DOI: 10.1109/ICASSP.2005.1416426).

[7] M. Maadani, S. A. Motamedi, and H. Safdarkhani, "An adaptive rate and coding scheme for MIMO-enabled IEEE 802.11-based Soft-Real-Time wireless sensor and actuator networks", in *Proc. 3rd Int. Conf. on Computer Research and Development*, Shanghai, China, vol. 1, pp. 439–443 (DOI: 10.1109/ICCRD.2011.5764053).

[8] S. K. Jayaweera, "Energy efficient virtual MIMO-based cooperative communications for wireless sensor networks", in *Proc. Int. Conf. on Intell. Sensing and Information Process.*, Chennai, India, 2005 (DOI: 10.1109/ICISIP.2005.1529410).

[9] D. Sathian, R. Baskaran, and P. Dhavachelvan, "A trustworthy energy efficient MIMO routing algorithm based on game theory for WSN", in *Proc. IEEE Int. Conf. on Adv. in Engin., Sci. and Manag. ICAESM-2012*, Nagapattinam, Tamil Nadu, India, 2012, pp. 499–502 [Online]. Available: https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6215895

[10] Y. Zuo, Q. Gao, and L. Fei, "Energy optimization of wireless sensor networks through cooperative MIMO with data aggregation", in *Proc. of the 21st Ann. IEEE Int. Symp. on Pers., Indoor and Mob. Radio Commun.*, Instanbul, Turkey, 2010, pp. 1602–1607 (DOI: 10.1109/PIMRC.2010.5671946).

[11] Y. Qin, Q. Tang, Y. Liang, X. Yue, and X. Li, "An energy-efficient cooperative MIMO scheme for wireless sensor networks based on clustering", in *Proc. of the 14th IEEE Int. Conf. on Comput. Sci. and Engin.*, Dalian, China, 2011, pp. 471–474 (DOI: 10.1109/CSE.2011.86).

[12] K. C. Reddy, G. D. Devanagavi, and M. N. Thippeswamy, "QoS oriented and energy efficient routing protocol for cooperative MIMO based mobile WSN: Q-E2RPC", *J. of Engin. Sci. and Technol. Rev.*, vol. 12, no. 1, 2019 (DOI: 10.25103/jestr.121.25).

[13] X. H. Li, M. Chen, and W. Liu, "Cooperative transmissions in wireless sensor networks with imperfect synchronization", in Conference Record of the *38th Asilomar Conf. on Sig., Syst. and Comp.*, Pacific Grove, CA, USA, 2004, vol. 1, pp. 1281–1285 (DOI: 10.1109/ACSSC.2004.1399348).

[14] S. Cui, A. J. Goldsmith, and A. Bahai, "Modulation optimization under energy constraints", in *Proc. of the IEEE Int. Conf. on Commun. ICC'03*, Anchorage, AK, USA, 2003, vol. 4, pp. 2805–2811 (DOI: 10.1109/ICC.2003.1204511).

[15] J. G. Proakis and M. Salehi, *Digital Communications*, 5th ed. New York: McGraw-Hill, 2008 (ISBN: 9780072957167).

[16] M. Xiao, L. S. Huang, and H. L. Xu, "Virtual MIMO multicast-based multihop transmission scheme for wireless sensor networks", *J. of Chinese Comp. Syst.*, vol. 33, no. 1, pp. 18–23, 2012 [Online]. Available: http://xwxt.sict.ac.cn/EN/volumn/volumn_1295.shtml [in Chinese].

[17] S. K. Jayaweera, "Energy analysis of MIMO techniques in wireless sensor networks", in *Proc. of the 38th Conf. on Inform. Sci. and Syst. CISS 2004*, Princeton, New Jersey, USA, 2004 [Online]. Available: https://pdfs.semanticscholar.org/186c/a8081ed1238d52f1da147b2aeb665ee1a00e.pdf

[18] Y. Gai, L. Zhang, and X. Shan, "Energy efficiency of cooperative MIMO with data aggregation in wireless sensor networks", in *Proc. of the IEEE Wirel. Commun. and Network. Conf.*, Kowloon, China, 2007, pp. 791–796 (DOI: 10.1109/WCNC.2007.151).

[19] K. Xu, W. Liu, Z. Yang, G. Cheng, and Y. Li, "An end-to-end optimized cooperative transmission scheme for virtual MIMO sensor networks", in *Proc. of the 10th IEEE Singapore Int. Conf. on Commun. Syst.*, Singapore, 2006 (DOI: 10.1109/ICCS.2006.301370).

Kummathi Chenna Reddy is an Assistant Professor at the Department of Electronics and Communication Engineering, Brindavan College of Engineering. He received his Ph.D., M.E., and B.Tech. degrees in Electronics and Communication Engineering. His research interests include wireless sensor networks, neural networks, and the Internet of Things.

E-mail: chenna.cr@gmail.com
Department of Electronics and Communication Engineering
Brindavan College of Engineering
Bangalore, India

Geetha D. Devanagavi received her Ph.D., M.Tech., and B.E. degrees in 2014, 2005, and 1993, respectively. She is currently working as a Professor at Reva University. She has 21 years of teaching experience. Her research interests include wireless sensor networks, network security, and computer networks.

E-mail: dgeetha@reva.edu.in
School of Electronics and Communication
REVA University
Bangalore, India

Thippeswamy M. N. is currently working as Professor at CSE, NMIT, Bangalore, holds a B.E. in Computer Science and Engineering from Kuvempu University, India, M.Tech. in Computer Science and Engineering from VTU, India, and Ph.D. in Engineering from the School of Engineering (Electrical, Electronic and Computer Engineering), Howard College Campus, University of KwaZulu-Natal, Durban, South Africa. Currently, his research interests focus on the Internet of Things, big data analytics, wireless ad-hoc and sensor networks, and cognitive radio, with primary emphasis placed on design and analysis of MAC and routing protocols.

E-mail: thippeswamymn@nmit.ac.in
Department of Computer Science
Nitte Meenakshi Institute of Technology
Bangalore, India.