An Energy-Efficient Approach for Large Scale Opportunistic Networks

Conference Paper · August 2018

3 authors:

Hemant Kumar Narsani
National University of Sciences and Technology

Syed Ali Hassan
National University of Sciences & Technology

Sajid Saleem
National University of Sciences and Technology

An Energy-Efficient Approach for Large Scale Opportunistic Networks

Hemant Kumar Narsani, Syed Ali Hassan, and Sajid Saleem
School of Electrical Engineering & Computer Science (SEECS),
National University of Sciences & Technology (NUST), Islamabad, 44000, Pakistan.
Email: {hkumar.msee16seecs, ali.hassan, sajid.saleem}@seecs.edu.pk

***Abstract*—This paper studies the performance of a cooperative opportunistic large array (OLA) network, in which the nodes are deployed randomly in a strip-shaped fashion. Specifically, the source and the destination nodes are separated by a large distance and a number of randomly deployed relay nodes help the source message to be delivered to the destination using multi-hop cooperation strategy. The performance of network is carried out in terms of the success rate and the average number of hops to reach the destination. The reliability of the OLA network is increased, when the same message is transmitted by a group of nodes in multiple hops by exploiting spatial diversity gains. Towards the end, energy efficiency in the networks can be achieved by limiting few nodes in each hop without compromising on the quality of service (QOS). The paper summarizes and compares the performance of various network topologies in terms of energy efficiency and outage probability.**

***Index Terms*—Cooperative communication, opportunistic large array, energy efficiency, multi-hop network, quality of service.**

I. Introduction

The performance of wireless sensor networks (WSNs) and cellular networks strongly depends on the wireless channel characteristics. Because of the channel impairments such as path loss and multi-path fading, reliable communication between network entities is a challenging task. However, reliable communications in WSNs and other networks with such impairments can be made possible with nodes transmitting in cooperation [1], resulting in increased signal-to-noise ratio (SNR) at the receiver. This scheme, known as cooperative transmission (CT), has attracted a lot of attention in the previous years. CT is a physical layer communication technique, where the same message signal propagates through wireless medium via uncorrelated fading channels which provides spatial diversity [2].

Opportunistic Large Array (OLA) is a prominent technique of CT [3], which is used to broadcast messages to distant nodes in a dense WSN. In transmission of basic OLA, a source node broadcasts its message to all nodes in its vicinity. All the nodes that receive this message try to decode it and the nodes that can decode the message, forward the message to other nodes in their vicinity without any prior sharing of control messages or any coordination with one another; thereby contributing diversity. This phenomenon of signal transmission from one cluster of nodes to other constitutes multi-hop communications and the nodes that decode the message in any cluster are called decode-and-forward (DF) nodes. The process continues until the message is received either at the destination node or disseminated over the entire network as a broadcast. OLA is a faster and reliable transmission technique which can be used for unicasting or broadcasting in ad hoc networks [4-6]. The primary advantage of using an OLA protocol is that it does not require any prior location of cooperating nodes which makes it suitable for ad hoc networks in terms of scalability. The other benefits of this protocol are simple and inexpensive routing [6], range extension [7] and energy efficiency [8].

The proposed model for a strip-shaped OLA network in [4] assumes continuum of nodes in the network which implies that the node density in an area goes to infinity while keeping the total transmit power constant per unit area. This leads to infinite signal propagation over the network. This assumption of continuum of nodes confined its application to networks with very high node density. However, it is shown in [9] that a finite node density cannot lead to an infinite broadcast and that the path loss exponent plays a major role in controlling the broadcast region. In [10], the authors studied the OLA line network with finite node density and modeled the node locations with Bernoulli point process. The model is then extended in [11] to a strip-shaped network with deterministic hop boundaries. Specifically, the authors model an ad hoc network where the number of nodes in each hop is known a priori. Moreover, fixed hop boundaries were assumed and Markov chain was derived to study the characteristics of multi-hop transmissions over the network. The extended model in [12] was studied with random number of nodes per hop and fixed hop boundaries. In [13], the authors introduced the concept of limiting the node participation for conserving the energy during transmission in a 1D and 2D finite node density networks. However, nodes distribution is deterministic. In [14], the authors analyzed the performance of random node locations with finite node density in a strip-shaped network where nodes are uniformly distributed. Moreover, the algorithm for conserving energy was also proposed in terms of the fraction energy saved in quantified.

In this paper, we study the propagation characteristics in an OLA network where the nodes are deployed in such a manner that they follow a uniform distribution over a certain area and the distance between different nodes is also a random process. The number of nodes in each level as well as the boundaries of the levels are kept random. The transmission model is similar to typical OLA, where the transmission of the message signal from a source node to a far-off destination node forms uneven levels or hops in terms of sizes and with random number of DF nodes in each hop. The coverage probability is analyzed for a variety of node densities, powers and decoding threshold values. The study provides an indepth performance analysis of OLA broadcasts in finite density scenarios and transmission characteristics with respect to various network parameters. A study of network longevity is further carried out in a way in which few nodes are deliberately limited to take participate in transmission to conserve significant amount of energy. The paper then concludes at the end with a note on future works.

II. SYSTEM MODEL

In this section, we describe network arrangement and assumptions used for modeling cooperative multi-hop ad hoc network.

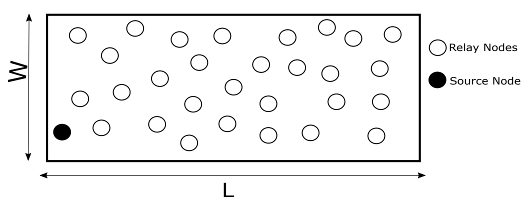

Fig. 1. Random deployment of nodes in a 2D strip-shaped network.

A. Basic OLA

Consider a strip-shaped network in which nodes are randomly deployed with a finite node density as shown in Fig. 1. The filled black node is considered as a source node which broadcasts its message signal. The message is received by all other nodes in the vicinity and each node tries to decode the message. A node can successfully decode the message depending on transmit power, wireless channel impairments and decoding threshold. The nodes that successfully decode the message are called decode-and-forward (DF) nodes and these DF nodes become members of first level (or hop). The DF nodes will broadcast the message received from source to the nodes ahead in the next time slot cooperatively and level 2 is formed. Note that the nodes in level 2 combine signals from the previous level nodes, thereby obtaining a diversity gain. This action of retransmissions continues and subsequent levels are formed until the message signal is disseminated over the entire network or reached at a particular destination node. A node can successfully decode the signal, transmitted by a group of nodes in the previous level, if the accumulated received power is greater than the decoding threshold. The power received at each node of any level is a random variable (RV), and depends upon channel impairments such as path loss and multi-path fading.

It can be seen in Fig. 2 that a hop is formed opportunistically during entire transmission process and there are no fixed boundaries between the nodes of two levels. The levels or hops are denoted by $k-1$, k, $k+1$ and so on. A node of any level can be a member of many levels in different sessions of CT because of random boundaries, channel characteristics

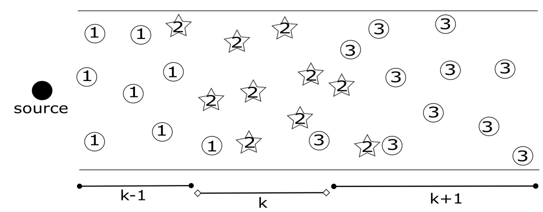

Fig. 2. The propagation of transmission from source to different nodes in different levels.

and geometry. In a general manner, each level or hop contains a random number of nodes and the number of hops required to deliver a message to a destination node or a given distance is depend upon network parameters. A node can successfully decode a message if its received SNR, after post detection combining, is above a decoding threshold. Fig. 3 shows the formation of a virtual multiple input single-output (MISO) scenario by which reliability is achieved because of spatial diversity.

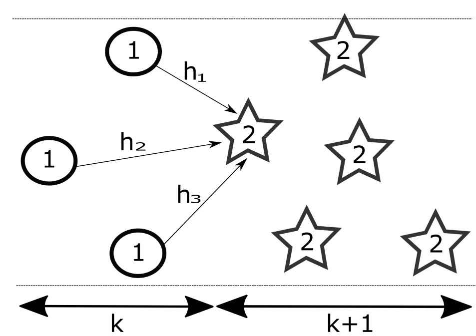

Fig. 3. Node of next level receives multiple copies of a same message signal from the nodes of previous level forms a MISO scenario.

In basic OLA, let Φ_k denotes a set, which contains the DF nodes at a level k, then the power received at a jth node of level $k+1$ is given as

$$P_{r_j}(k+1) = P_t \sum_{i \epsilon \Phi_k} \frac{h_{ij}}{d_{ij}^{\alpha}}, \tag{1}$$

where P_t is the transmit power of a node, h_{ij} denotes the effects of Rayleigh flat fading modeled with unit mean exponential RV, d is the Euclidean distance between node i of level k and node j of level $k+1$ and α represents the path loss exponent where its range varies between 2-4. The outage probability of the node j is calculated as

$$P_o = \mathbb{P}\{P_{r_j}(k+1) < \tau\}, \tag{2}$$

where τ is the decoding threshold.

B. OLA Threshold (OLA-T)

The network can be made energy efficient when a few nodes of any level participate in forward transmission instead of all DF nodes of that level. However, it should be noticed that due to limited participation, the diversity gain at a receiving node becomes small, which affects the quality of service

(QoS). In Fig. 4, the circular nodes are DF nodes of level 1 and are ready to forward the same message to form level 2. However, as the dotted nodes are near to source, their contribution in providing diversity gain to a receiving node of level 2 has a minimal effect because of large path loss between them and the nodes of level 2. Therefore, it is better to limit these nodes for transmission and allow only those DF nodes for transmission, which are in the vicinity of level 2 nodes. In this case, the nodes of one level are divided into two subsets; idle transmitters and active transmitters. The size of the active nodes selected for transmission is based on percentage participation. For instance, if there are 50 DF nodes in a level, and 10% participation of DF nodes is allowed for retransmission, then only 5 DF nodes will be active and the other 45 become idle.

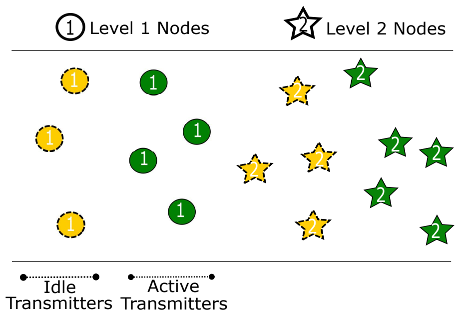

Fig. 4. DF nodes in levels are divided in two subsets.

III. RESULTS AND ANALYSIS

In this section, we discuss the performance of the network in terms of success probability, latency and energy efficiency. We consider a network having a length of 1500m and a width of 50m where 500 nodes are deployed uniformly in this area. The source node is one of these 500 nodes and is located at the start of the network. The destination node is considered as the farthest node from the source node in this strip-shaped network. The channel model includes Rayleigh fading and path loss.

Fig. 5 shows the relationship between outage probability and transmit power for different values of path loss exponent, α. The outage event occurs when the destination is unable to receive the data. This may arise due to the fact that a running OLA dies down at an intermediate stage before the destination is reached. The transmit power of each node in the network remains the same for all nodes. It can be seen that at α = 2, the outage probability of the network is least as expected. As the value of α increases, the performance of the system becomes worse. For example, when α = 2.5, each node requires about 6dBm of transmit power to achieve an outage probability of 10%, which is 3dBm higher than that required at α = 2 to get the same outage probability.

In Fig. 6, the average number of hops from the source node to the destination node is calculated at multiple transmit power of nodes for different values of α. It can be seen that less number of hops are required for the message to reach the destination node when path loss exponent is small. As seen in Fig. 6, about 15 hops on average is taken by the message to reach the destination node with outage probability of 10% for α = 2, whereas 50 hops on average are required with α = 2.5 to maintain the same outage probability. Hence path loss exponent plays a detrimental role in coverage of OLA multi-hop networks.

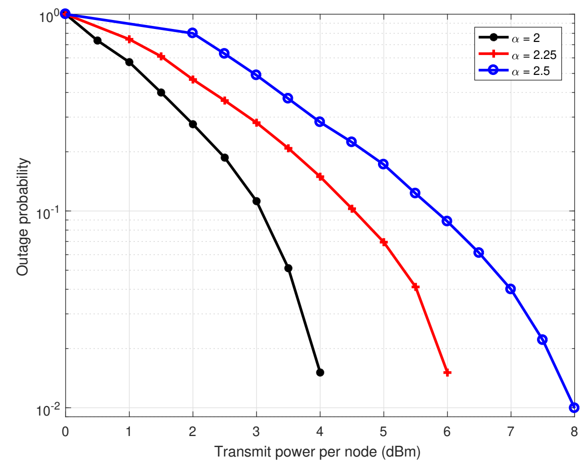

Fig. 5. Outage probability against transmit power for three different values of α with node density = 500, decoding threshold = 0.5, L = 1500, W = 50.

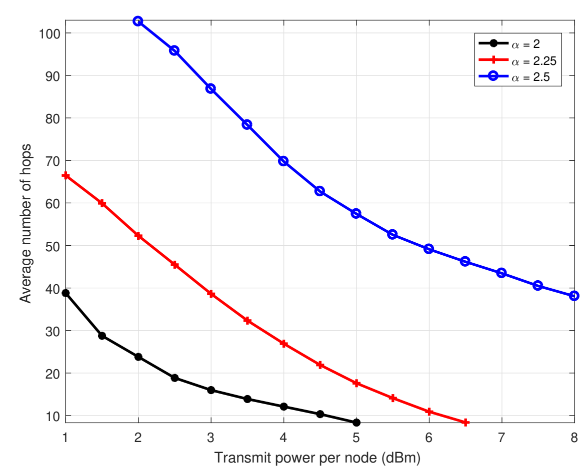

Fig. 6. Average hops against transmit power for three different values of α with node density = 500, decoding threshold = 0.5, L = 1500, W = 50.

Fig. 7 depicts the relationship between node density, success probability and average hops for different values of α. The figure shows that the success probability increases for all values of α when the node density increases while the average number of hops decreases. The reason is that as the number of nodes per unit area becomes large, diversity gain increases and therefore, the chances of node participating in a level and likelihood of decoding increases. As more nodes engage in retransmission, it is less probable that the message fails to reach the destination. For the same reason of SNR advantage, a message takes fewer hops from source to destination when the node density becomes large as shown in Fig. 7. It can be seen that for $\alpha = 2.5$ when the node density is 550, 100 hops on the average are required by a message to reach the destination with success probability of only 45%. However, if the node density is increased to 750, average hops becomes 90 with a success rate of around 90%.

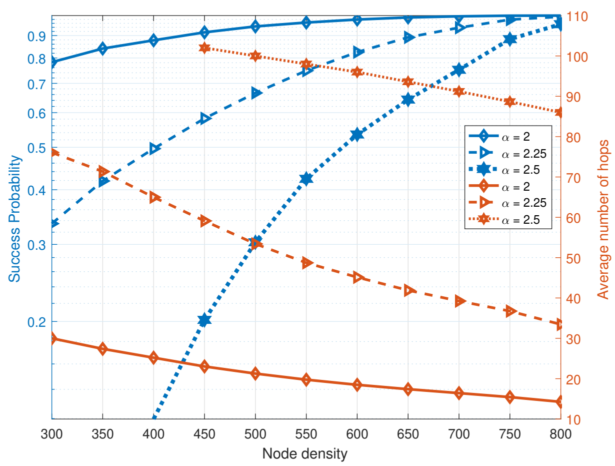

Fig. 7. Success probability and Average hops against node density for three different values of α with transmit power per node = 2dBm, decoding threshold = 0.5 , L = 1500, W = 50.

Fig. 8 provides information of power against success probability and average hops for different node densities at $\alpha = 2$. As described in Fig. 5 that by increasing transmit power of nodes, the outage probability decreases, however it decreases rapidly when node density is high as shown in Fig. 8. For a node density of 500, the node are located near to each other as compared to a node density of 400, therefore, the success increases. For the same reason, a message reaches earlier at the destination when the node density is high. At 3.5dBm, for a node density of 400, on average 21 hops are required for a message to be received by destination node with success probability of about 94%, whereas about 18 hops on average are required when the node density is 500 with success probability of about 98%.

We now focus on the results of OLA-T network for which we demonstrate the result of energy efficiency. In Table I, the performance of three networks is summarized in terms of power per node. These networks are defined as X, Y and Z. The node density for each network is 100 and the decoding threshold is same for all topologies. The percentage participation from 10% - 90% shown in table defines the percentage of nodes allowed in each hop for retransmitting the received message. These nodes are called active nodes and the selection of these nodes is on the basis of path loss to the next level nodes. The nodes near the boundary of the next level are chosen as active nodes. The 100% shows the basic OLA in which all nodes that decode the message retransmit it. For

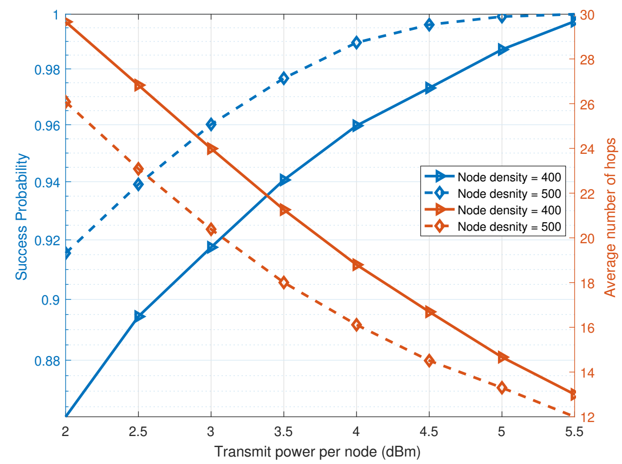

Fig. 8. Success probability and average hops against transmit power for different node densities, L = 1500, W = 50.

each network with its corresponding percentage participation, different transmit power (in dBm) per node required for maintaining a success probability of 80% is also provided. Lastly, Ω denotes the ratio of total active nodes to total DF nodes from the source node to the destination. It can be seen that when the percentage participation value is minimum, more power per node is required to guarantee a success probability of atleast 80% at the destination. It can be further noticed that average number of hops approximately remains the same for different percentage participation. Because of this limitation in participation of nodes, there will be less effective diversity gain in each hop. As the percentage participation increases, diversity gain increases in each hop even at less power per node. It can be further noticed that when nodes are separated by larger distance between them, as in network Z, more power per nodes is needed to transmit the message to destination node.

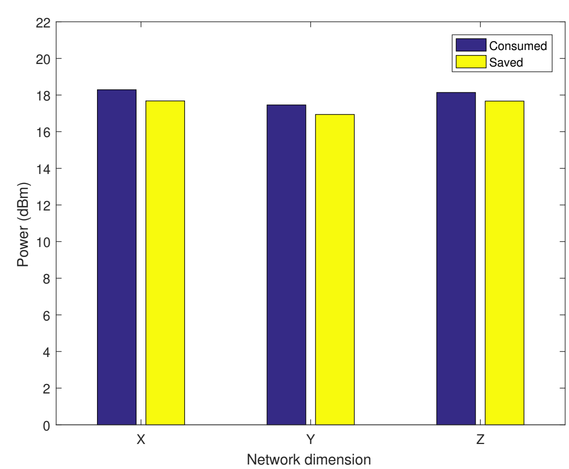

Fig. 9. Fraction of energy saved and consumed at active nodes 50% for three different networks

TABLE I
THE PERFORMANCE OF OLA-T OF THREE DIFFERENT NETWORKS

Dimension		Percentage participation									
		10	20	30	40	50	60	70	80	90	100/Basic OLA
X= 300 x 50	Ω	10.23/50.08	17.14 /63.75	28.43/83.26	38.22/83.96	44.92/83.96	56.83 /87.43	66.70 /88.47	73.78 /87.53	83.33/88.88	1
	Power(dBm)	4.10	3.15	2.35	1.90	1.80	1.55	1.50	1.50	1.48	1.48
	Hops	10.49	11.25	11.47	11.64	10.97	10.59	9.84	9.26	8.77	8.63
Y= 200 x 50	Ω	8.62 /45.83	15.79/62.05	25.95/73.36	35.36 /78.04	42.83/80.87	54.19/84.27	63.39/84.90	71.38/85.27	81.20/86.70	1
	Power(dBm)	2.80	2.20	1.60	1.20	1.10	1.0	0.90	0.90	0.90	0.90
	Hops	8.70	8.80	8.96	9.76	9.48	8.71	8.71	8.15	7.74	7.59
Z= 200 x 100	Ω	7.66/48.26	13.54 /56.59	20.59/59.51	28.62/65.09	34.29/65.05	44.40/69.93	52.21 /71.06	60.21/72.35	68.38/73.45	1
	Power(dBm)	7.20	5.00	3.50	3.00	2.85	2.75	2.75	2.70	2.70	2.70
	Hops	6.04	6.35	7.00	6.89	6.67	5.85	5.51	5.34	5.22	5.13

Fig. 9 describes the energy efficiency of the three networks shown in Table I at 50% percentage participation. For the network X, there are on average 44.92 active nodes which transmitted the message from hop to hop up to destination with equal transmission power of 1.80dBm while maintaining 80% success probability. Therefore, the total energy consumed from source to destination is 18.29dBm while saving 17.68dBm by limiting other nodes to participate. This implies that about 50% of energy is saved for this network compared to basic OLA. Likewise, energy consumed for networks Y and Z is 17.46dBm and 18.14dBm, respectively while conserving 16.94dBm and 17.67dBm, respectively as shown in Fig. 9. Comparing to basic OLA, where all DF nodes transmit the message, almost 50% of the energy is conserved. However, in basic OLA a node requires minimum transmit power to broadcasts its message, but on the same time, since all nodes in basic OLA take part in transmission, the power consumed from source to destination is much higher compare to OLA-T. Hence it can be observed that OLA-T provides energy efficient approach than basic OLA and can be used in various cooperative transmission-based applications.

IV. CONCLUSION

In this paper, we analyzed the performance of a basic OLA network in which the nodes are deployed randomly in strip-shaped scenario. The performance is carried out in terms of the success rate, the average hops and the node density. We then examined network performance in terms of energy efficiency using OLA-T protocol. We concluded that the energy efficiency of network can be achieved by limiting few nodes to participate in forward transmission. However, higher transmit power per node is required in OLA-T network, to achieve a desired QOS. The future direction of this work would be to study the effects of multiple packets transmission in OLA that may induce interference and limit the success probability. To manage multiple sources that insert different packets simultaneously is another important direction of research.

REFERENCES

[1] A. Nosratinia, T. E. Hunter and A. Hedayat, "Cooperative communication in wireless networks," in *IEEE Communications Magazine*, vol. 42, no. 10, pp. 74-80, Oct. 2004.

[2] J. N. Laneman, D. N. C. Tse and G. W. Wornell, "Cooperative diversity in wireless networks: Efficient protocols and outage behavior," in *IEEE Transactions on Information Theory*, vol. 50, no. 12, pp. 3062-3080, Dec. 2004.

[3] A. Scaglione and Yao-Win Hong, "Opportunistic large arrays: cooperative transmission in wireless multihop ad hoc networks to reach far distances," in *IEEE Transactions on Signal Processing*, vol. 51, no. 8, pp. 2082-2092, Aug. 2003.

[4] B. Sirkeci-Mersen and A. Scaglione, "A continuum approach to dense wireless networks with cooperation," Proceedings *IEEE 24th Annual Joint Conference of the IEEE Computer and Communications Societies*., 2005, pp. 2755-2763 vol. 4.

[5] B. Sirkeci-Mergen, A. Scaglione and G. Mergen, "Asymptotic analysis of multistage cooperative broadcast in wireless networks," in *IEEE Transactions on Information Theory*, vol. 52, no. 6, pp. 2531-2550, June 2006.

[6] L. Thanayankizil, A. Kailas, and M.A. Ingram, "Routing protocols for wireless sensor networks that have an opportunistic large array (OLA) physical layer,"*Ad Hoc and Sensor Wireless Networks, Special Issue on Sensor Technologies and Applications*, Vol. 8, no. 1-2, p. 79-117, 2009.

[7] H. Jung, Y. J. Chang and M. A. Ingram, "Experimental range extension of concurrent cooperative transmission in indoor environments at 2.4GHz," *Military Communications Conference*, San Jose, CA, 2010, pp. 148-153.

[8] Yao-Win Hong and A. Scaglione, "Energy-efficient broadcasting with cooperative transmissions in wireless sensor networks," in *IEEE transactions on wireless communications*, vol. 5, no. 10, pp. 2844-2855, Oct. 2006.

[9] C. Capar, D. Goeckel and D. Towsley, "Broadcast analysis for extended cooperative wireless networks," in *IEEE Transactions on Information Theory*, vol. 59, no. 9, pp. 5805-5810, Sept. 2013.

[10] S. A. Hassan and M. A. Ingram, "Analysis of an opportunistic large array line network with Bernoulli node deployment," in *IET Communications*, vol. 8, no. 1, pp. 19-26, Jan. 2014.

[11] A. Afzal and S. A. Hassan, "Stochastic modeling of cooperative multi-hop strip networks with fixed hop boundaries," in *IEEE Transactions on Wireless Communications*, vol. 13, no. 8, pp. 4146-4155, Aug. 2014.

[12] M. Ahsen and S. A. Hassan, "A Poisson point process model for coverage analysis of multi-hop cooperative networks," 2015 *International Wireless Communications and Mobile Computing Conference (IWCMC)*, Dubrovnik, 2015, pp. 442-447.

[13] R. I. Ansari and S. A. Hassan, "Opportunistic large array with limited participation: An energy-efficient cooperative multi-hop network," 2014 *International Conference on Computing, Networking and Communications (ICNC)*, Honolulu, HI, 2014, pp. 831-835.

[14] M. Ahsen, S. A. Hassan and D. N. K. Jayakody, "Propagation modeling in large-scale cooperative multi-hop ad hoc networks," in *IEEE Access*, vol. 4, pp. 8925-8937, 2016.