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Fragment-based transmission using minimum power consumed routing (FBTMPCR) algorithm of a MIMO integrated MANET

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Abstract: The establishment of an efficient broadcast routing technique in a multiple input multiple output (MIMO)-based mobile ad hoc network is a challenge in wireless communication. MIMO configuration provides enhancement of data throughput even under conditions of interference and multipath fading. Improvement of transmission efficiency by increasing saturation throughput, reducing transmission delay, and minimizing bit error rate is the main motivation of the present work. In this paper a hybrid routing algorithm, fragment-based transmission using minimum power consumed routing, has been developed. It is an integration of the cooperative transmission process and fragmentation of packet payload. The routing algorithm is developed on selecting the best suitable relay node considering effective received signal strength and probability of successful packet transmission. The broadcasting mechanism is done by using multiple fragment of packet transmission through MIMO channel by using a suitable relay node. The performance analysis of this proposed routing algorithm increases the signal to noise interference ratio, resulting in minimization of BER, improvement of saturation throughput, and reduced transmission delay.

Key words: Mobile ad hoc network, multiple input multiple output, cooperative transmission, fragmentation, throughput, transmission delay

1. Introduction

Advancements in communication systems enable mobile ad hoc networks (MANETs) to broadcast information packets in any hazardous environment. Multiple input multiple output (MIMO) technology with multiple antenna elements serves a number of users' equipment simultaneously sharing mutual resources. This system implemented with a MANET improves the transmission rate/saturation throughput of the network. One of the efficient methods of transmitting packets from source to destination receiver node in a MANET is broadcasting, and designing an efficient broadcasting protocol is the most demanding task in a MIMO integrated MANET. Mobility, dynamic topology, and resource sharing are the unique characteristics of MIMO integrated MANETs. The mobility of these nodes changes the network topology dynamically, causing frequent path failures. Packet broadcasting of a MIMO implemented MANET is mainly done in a resource sharing mechanism. The limited radio range of mobile nodes necessitates multihop transmission in the integrated network to establish communication, and packets transmitted from the valid mobile source node may not reach the target node in a single hop but by multiple hops through some intermediate node called a relay node. Selection of the intermediate node is an important criterion as these nodes use valuable resources of the network like battery power and bandwidth [1,2]. Packet forwarding to the entire mobile network, paging of a node, network

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management, route discovery, and overhead control are served by this broadcasting method [3,4]. A different broadcasting technique has been proposed and studied by many researchers of which performance analysis of conventional routing protocol is done considering single hop and multihop routing [5]. In our work, we want to establish a multihop routing protocol for a MIMO integrated ad hoc network in complicated terrain. We propose a routing protocol considering all these parameters in an energy efficient way, with faster transmission by integrating a fragmentation technique.

In this work, we propose a fragment-based transmission using minimum power consumed routing (FBTMPCR) protocol that introduces and improves the packet forwarding strategy for a MIMO integrated MANET by incorporating a fragmentation technique. This increases the signal to noise interference ratio (SNIR), improving saturation throughput, and reducing transmission delay of the network. The rest of the paper is organized as follows. Related work is described in section 2 and section 3 explains the rationality of the relay node. The proposed relay node selection method is described in section 4. The conventional fragmentation technique followed by estimation of saturation throughput and fragment length optimization is described in section 5. In section 6, the proposed FBTMPCR algorithm is described. Finally, section 7 concludes the paper, summarizing our main ideas.

2. Related work

This section demonstrates some works regarding the routing protocol of the MIMO integrated MANET. Performance comparison of different routing protocol is introduced in [5] based on metric value. In [6] the authors compare the performance of protocols in NS-2 simulation environment and indicated improvement. In the OPNET environment, simulation of small link conventional routing is done in [7]. Comparison of the performance of single-hop and multihop routing followed by simulation is done in [8,9] for an ordinary ad hoc network. A routing protocol has been analyzed in [10,11], where distance, metric value, etc. are considered parameters. In [12] the authors select a relay node for the routing process based on a coding approach and real-time channel state approach for a cooperative network. In the first case the authors describe the basic idea that each user must transmit increasing redundant information for a cooperative partner and in the second case the basic principle is to transmit real-time channel information of the source node to a relay node and relay to destination node. In [13] the authors describe the relay node selection algorithm using the stable matching concept. Here the authors focus on 'selective' decode-forward transmission, where the relay station only decodes the data and retransmits the data to the destination. The routing process is done by the selected relay node. In our hybrid routing algorithm we develop the best suitable relay node selection process based on effective transmission power related to propagation loss and probability of successful transmission.

3. Rationality of relay node

The conventional flooding mechanism has some limitations due to the limited power of mobile nodes, higher interference, and fading effect. A pragmatic alternative will be to replace a single long range link by a chain of short range links connecting series of intermediate nodes between source and destination. The intermediate node receives the signal from the source, processes, and retransmits to the next node of the chain. The intermediate nodes are known as relay nodes and by multiple hopping through relay nodes, the packet reaches the destination node. The relay node provides seamless communication even if a node becomes partially inefficient due to the following effects such as energy depletion and node failures. As interference is less in relay communication the signal to interference ratio will be higher over long range communication. Higher throughput may be achieved by multihop transmission over direct communication if the numbers of hops are optimized. Now each node has its own processing time. As the transmission process occurs considering multiple hops, total processing time is increased. Here we propose a scheme to reduce this delay by fragmenting a long frame into a smaller frame and transmitted simultaneously through the MIMO channel. Considering the above two points we propose a routing method of wireless ad hoc communication, i.e. MIMO integrated MANET communication.

4. Proposed relay node selection method

A novel method of relay node selection is proposed here. The nodes that are considered here are randomly distributed in a complex terrain and simplicity of calculation having uniform sensitivity (S), which is defined as minimum received signal strength (RSS_{min}), is necessary to generate adequate usable power output in the presence of noise. The received signal strength at any node from the parent node will be affected due to propagation loss as a result of multipath fading and loss of packet information due to collision over multichannel interference. The variation in signal strength at any distant point due to the combined effect of propagation loss and multipath fading will have spatial and temporal variations. The nature of spatial variations in received signal strength is shown in Figure 1. The continuous fluctuation of the signal strength may have a ping-pong effect at the receiving node. To avoid this effect we select the relay node such that the average value of the received signal strength is little more than the sensitivity S of the mobile node. The value of the signal strength is proposed as Th, which is ΔS above the sensitivity of the mobile node called threshold level, as shown in Figure 1. If the received signal strength of any node is less than the threshold level then the particular node will not be considered as a relay node. Let P_c be the probability of collision due to multichannel interference; then $(1 - P_c)$ will be the probability of successful transmission (P_s) in a particular terrain.

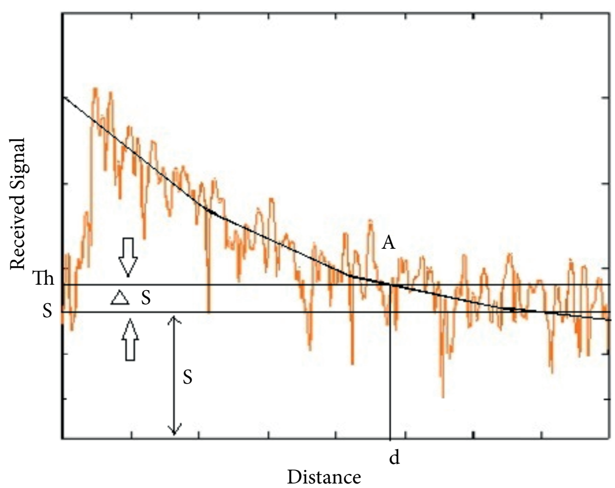

Figure 1. Received signal strength of mobile node.

From the above consideration, we find that for selection of a suitable relay node, there are two important points to be considered: (i) Received signal strength should be above the threshold, that is $P_r \geq P_{th}$, and (ii) Probability of collision should be minimum, that is $P_c \leq x(0 \leq x \leq 1)$. We define a term P_e as the effective received power for a successful reception at the particular node, which is the product of P_r and P_s.

$$\text{That means } (1 - P_c) * P_r \geq (1 - x) * P_{th}, \tag{1}$$

where $P_r \geq P_{th}$; $P_c \leq x$.

The number of nodes in the ad hoc network between source and destination satisfying the above condition (shown in Eq. (1)) may be considered as relay nodes for transmission. Now for a particular case where more than one node satisfies the above condition, the particular node is selected as the first stage relay node where RSS is minimum (minimum received signal strength can optimize the hop distance) and if the RSS value of two nodes is the same then we select that relay node for which $(1 - P_c)$ is maximum. The second phase relay node is selected considering the first phase relay node as a source node and the process of hopping through relay nodes will continue until the information reaches the final destination node.

4.1. Derivation of propagation loss

Propagation loss (P_L) for a MIMO integrated MANET in different terrain has already been calculated in [14], as shown in the subsequent section. Let PL_{1-2} be the propagation loss between the nodes with multiple antennas that are placed in a forest area, PL_{2-3} be the propagation loss between two nodes with multiple antennas that are in a free space (outdoor propagation loss) propagation environment, PL_{3-4} represents combination of free space propagation loss and indoor propagation loss where one node is situated outside the building and another one is inside the building, PL_{4-5} represents the indoor propagation loss where both nodes are placed inside the building, and PL_{5-6} is the indoor propagation loss where two ad hoc nodes are placed within the building but on different floors. Thus propagation loss models are expressed as

$$PL_{1-2} = -10\log_{10}\left(\frac{1}{MN}\sum_{f}\sum_{i=1}^{M}\sum_{j=1}^{N}\left\{[H_{i,j}]^T * [I]_{N*1}\right\} \times \frac{d^4 d_0^2}{R^2 f^2}\right), \tag{2}$$

where d is forested depth in meters, R is radius of ad hoc nodes, d_0 is distance between two ad hoc nodes, and f is frequency of the operating signal.

$$PL_{2-3} = -10\log_{10}\left(\frac{1}{MN}\sum_{f}\sum_{i=1}^{M}\sum_{j=1}^{N}\left\{[H_{i,j}]^T * [I]_{N*1}\right\} * (Q * A_r)\right) \tag{3}$$

$$(Q * A_r) = \left(\frac{1}{2}\frac{e^2}{120\pi}\right) * \left(\frac{\lambda^2 g_r}{4\pi l_r}\right), \tag{4}$$

where e is electric field strength

$$\begin{aligned} PL_{3-4} = &- 10\log_{10}\left(\frac{1}{MN}\sum_{f}\sum_{i=1}^{M}\sum_{j=1}^{N}\left\{[H_{i,j}]^T * [I]_{N*1}\right\} * (Q \times A_r)\right) \\ &+ \left[-10\log_{10}\left(\frac{1}{MN}\sum_{f}\sum_{i=1}^{M}\sum_{j=1}^{N}\left\{[H_{i,j}]^T * [I]_{N*1}\right\} * \left\{L_f F^{K_1} W^{K_2} R\right\}\right)\right], \end{aligned} \tag{5}$$

where F is floor loss (for the same floor the value of floor loss will be 2 to 3), W is wall loss, R is reflection loss, K_1 is number of floors, and K_2 is number of walls

$$PL_{4-5} = -10\log_{10}\left(\frac{1}{MN}\sum_{f}\sum_{i=1}^{M}\sum_{j=1}^{N}\left\{[H_{i,j}]^T * [I]_{N*1}\right\} \times \left\{L_f F^{K_1} W^{K_2} R\right\}\right) \tag{6}$$

$$PL_{5-6} = \left[-10\log_{10}\left(\frac{1}{MN} \sum_f \sum_{i=1}^{M} \sum_{j=1}^{N} \left\{ [H_{i,j}]^T * [I]_{N*1} \right\} \times \left\{ L_f F^{K_1} W^{K_2} R \right\} \right) \right] \tag{7}$$

If propagation loss is subtracted from transmitted signal the effective received signal strength can be easily estimated. Now to calculate P_e we need to find out the probability of collision (P_C) and hence proceed to relay node selection.

4.2. Derivation of probability of successful transmission

Let us consider a transmission process transmitting data from source node S to destination node D via relay node R. h_{sr}, h_{sd}, and h_{rd} are the channel gain of the source to relay, source to destination, and relay to the destination node. $P_S^{'}$ is transmit signal power and $P_r^{'}$ is received signal power. We know that the transmission probability of any channel depends on the channel capacity of the channel. The channel capacity of any channel is the maximum value of mutual information. Thus, to estimate the probability of transmission the first action needed is to calculate the mutual information of the channel. Mutual information of cooperative communication in the amplify-and-forward method [15] is found as

$$I_{SD}^{AF} = \log\left(1 + P_s^{'}\left|h_{sd}\right|^2 + \frac{P_s^{'}\left|h_{sr}\right|^2 P_r^{'}\left|h_{rd}\right|^2}{1 + P_s^{'}\left|h_{sr}\right|^2 + P_r^{'}\left|h_{rd}\right|^2} \right) \tag{8}$$

After this the mutual information of the MIMO channel is required to be estimated, as shown below:

$$\left(I_{SD}^{AF}\right)_{MIMO} = \log\left(1 + P_s^{'}\sum_i\sum_j \left|h_{sd}^{ij}\right|^2 + \frac{P_s^{'}\sum_i\sum_j \left|h_{sr}^{ij}\right|^2 P_r^{'}\sum_i\sum_j \left|h_{rd}^{ij}\right|^2}{1 + P_s^{'}\sum_i\sum_j \left|h_{sr}^{ij}\right|^2 + P_r^{'}\sum_i\sum_j \left|h_{rd}^{ij}\right|^2} \right), \tag{9}$$

where $i(1,2,..M)$ and $j(1,2,\ldots N)$ signify the number of transmitting and receiving antennas, and the channel capacity of the MIMO channel using the amplify-and-forward method is

$$(C_{AF})_{MIMO} = \max\left(I_{SD}^{AF}\right) \tag{10}$$

To estimate the probability density function of this transmitted signal we need to study the SNIR of the received signal as the CDF function that depends on the SNIR. The SNIR of the threshold value (β) of any channel is found by inverting the capacity function $\beta \propto C^{-1}$ [16], where β is used to generate the cumulative distributive function (CDF). From this, the estimation of the probability density function (PDF) of the received signal is done, which is expressed as

$$f_{y_i}(y) = (1-p_i)\,\delta(y) + p_i\left(\frac{n_i}{\omega_i}\right)^{n_i}\frac{1}{\Gamma(n_i)} y^{n_i-1} e^{-y^{n_i}/\omega_i}\, u(y), \tag{11}$$

where p_i is the active probability of a particular node n_i. signal at receiving end

$$y = [y_1, y_{2,}y_3, ..., y_n] \tag{12}$$

Now the probability of successful transmission

$$P_S = \int_0^n f_{y_i}(y)\, dy \tag{13}$$

And probability of collision

$$P_c = 1 - P_s \tag{14}$$

The intermediate relay node is estimated on the basis of propagation loss and the probability of successful transmission.

In this way, the final path or route for the transmission process from source to the destination node is evaluated. Multiple frames of the same packet can be transmitted simultaneously through the MIMO channel, reducing the processing time and improving the data security or reliability of the transmission.

5. Conventional fragmentation technique

Fragmentation is one of the transmission processes of a wireless communication system where longer frames are divided into smaller frames (fragments) and each fragment is transmitted independently to the destination. Each fragmented frame is encapsulated with the usual MAC header and FCS fields and all fragments must be individually acknowledged. A MAC service data unit (MSDU) is passed down from the LLC layer if the size of the MSDU is greater than the fragmentation threshold and it is divided into smaller fragments. Each fragment, namely a MAC protocol data unit (MPDU), becomes a MAC layer frame with a MAC header [17]. Fragmentation can be used to improve the transmission reliability in hostile wireless environments because the probability of successful transmission increases as the size of MPDU decreases. These MPDUs are put into the buffer at the transceiver, and none of them will be defragmented further. In the MIMO channel the entire fragment is transmitted simultaneously, which can reduce the transmission time. The performance of the wireless communication network can be evaluated in terms of QOS parameters like throughput and transmission delay.

5.1. Estimation of saturation throughput

We focus on the estimation of saturation throughput of the integrated network. Let any transmission process can be divided into t number of states [18]; then the average throughput of a typical user under the saturation condition can be expressed as

$$s = \frac{E[L]}{\sum_{i=1}^{t} T_i}, \tag{15}$$

where L is the length of the packet. E$[L]$ is the average packet payload size and T_i denotes the duration of state i. T_S is the average time of a successful transmission, $T_S^{'}$ is the average time of a successful transmission for multiple antenna systems, and T_C is the average duration of a collision. Under the RTS/CTS mechanism, T_S and T_C are given by

$$T_S = RTS + 3SIFS + CTS + OH + E[T_P] + ACK + DIFS + \delta \tag{16}$$

$$T_s^{'} = mRTS + DIFS + 2SIFS + nCTS + OH + E[T_p] + N_r ACK \tag{17}$$

$$T_C = RTS + DIFS + \delta, \tag{18}$$

where $E[Tp]$ is the average transmission duration for payload, δ is propagation delay, and m and n are the numbers of transmitting and receiving antennas of the MIMO integrated network.

5.2. Hop distance and fragment size optimization

Let traffic arrival rate at the kth node

$$\lambda_k = \sum_i L_{frag}.s' \tag{19}$$

And traffic arrival rate throughout the network (considering n number of nodes)

$$\lambda = \sum_i L_{frag}.s'.n, \tag{20}$$

where λ is total traffic arrival rate. S' is the throughput of a single node. Constant utilization factor $\rho = {}^{\lambda}/_{s'}$ gives the value of node density.

Let d denote total hop distance and D denote the total transmit distance or end to end distance to transmit a message.

Delay per hop

$$T_d = \frac{1}{1-\lambda} = \frac{{}^{1}/_{s}}{1-{}^{\lambda}/_{s}} = \frac{{}^{1}/_{s}}{1-\rho} \tag{21}$$

Total delay

$$T_h = T_d\,{}^{D}/_{d} \tag{22}$$

By differentiating Eq. (22) with respect to d, we can find that the optimal hop distance satisfies the condition

$$\frac{\partial T_h}{\partial d} = \frac{T_h}{d}. \tag{23}$$

The optimized value of hop distance d can optimize the number of node n as $\left(n = \pi d^2 \rho\right)$. To achieve maximum throughput node density ${}^{\lambda}/_{s}$ factor can also be optimized. Finally fragmentation length L_{frag} can be optimized to achieve maximum throughput.

$$E\left[T_P\right] = \frac{L}{\lambda} = \frac{L}{L_{frag}.s'}, \tag{24}$$

where S' is the throughput of a single node.

Therefore $E\left[T_p\right]$ decreases if L_{frag} increases. From Eq. (16) it is clear that total transmission time T_S is reduced. It is concluded that if L_{frag} increases then fragmentation error is also reduced.

5.3. Simulated results to improve saturation throughput

This section represents the simulation results that have been done in MATLAB environment and validate the proposed equations. Figure 2 depicts the simulation results for measuring throughput for different fragment sizes. If the fragment size increases, the throughput is decreased and the optimal fragment size depends on the BER. If the BER is known, the optimal fragment size can be selected. Optimization of throughput at different SNRs is shown in Figure 3, with varying fragment size.

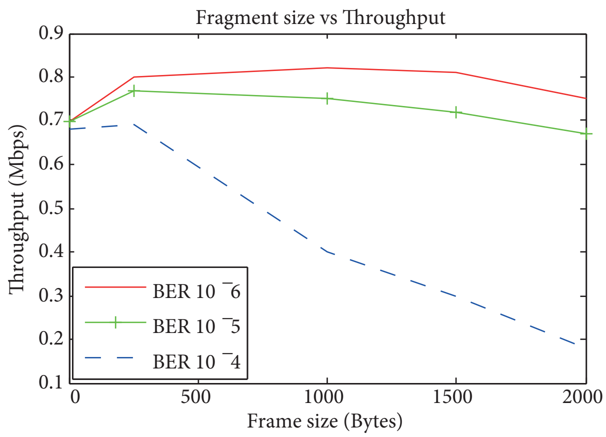

Figure 2. Fragment size versus throughput.

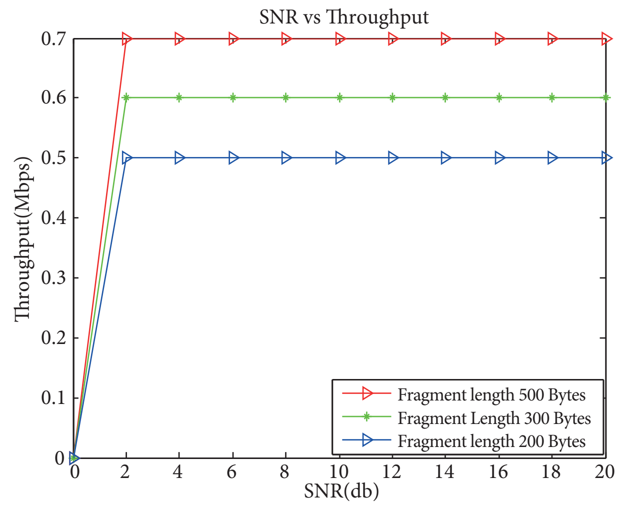

Figure 3. SNR versus throughput.

6. Proposed FBTMPCR algorithm

In the proposed algorithm, the best partner (suitable relay node) selection routing (optimized path) is decided on the basis of received power (Pr) by the node (estimated in section 4.1) and probability of successful transmission (P_s) (estimated in section 4.2). In the model network in Figure 4, 20 numbers of MIMO integrated ad hoc nodes are randomly distributed in combined terrain. Any ad hoc node first broadcasts the route update to its neighbors periodically. Each neighboring node that receives the updates for the first time rebroadcasts the update and marks the parent node from which it receives the data and the process continues until every node in the network has rebroadcast the update once and finds its parent. In this way, the routing table for effective power (P_e), multiplication of received power (P_r) by the receiving node and probability of successful transmission (P_s), is updated in a periodic way. From this routing table of the source node, we compare the total power of the entire surrounding node within its transmission range. Finally the best relay node is selected where the effective power is minimum. In this way, first phase relay node selection is done and this node becomes the source node for selection of next phase relay selection. Again the effective power is compared in the same way except at the parent node (from where the source receives the data) and the next relay node is selected with minimum power. This process repeats and updates the routing table until the data reach the destination. In Figure 4, source node 1 transmits the packet to its neighbors within its transmission range. Nodes 4, 6, and 16 are within the transmission range of source node 1. The source node floods the data to its neighbor's nodes and checks which node satisfies the condition for Eq. (1). If no node satisfies the condition then this node is not considered for the relay node selection process. In this case, nodes 4, 6, and 16 satisfy the condition of Eq. (1) and so all three nodes can be considered relay nodes. Within all these nodes, the received signal strength of nodes 6 and 16 is minimum so that particular node is considered a relay node where the probability of successful transmission is maximum (node 16 satisfies all these conditions); here node 16 is selected as first stage relay node. In the second stage node 16 acts as a source node and transmits the signal to all the nodes 3, 5, and 14 within transmission range except its parent node 1 to find the second phase relay node. The process continues until the transmitted signal reaches the final destination node 20. In this algorithm, the flooding node will not be considered as receiving node so that back propagation is prohibited. After selecting the route, the packet is transmitted in fragment form parallely by MIMO antenna system through multiple channels.

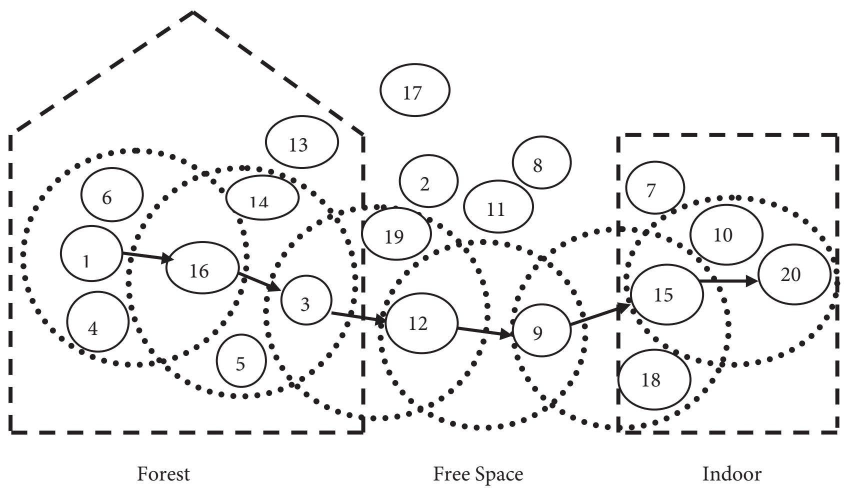

Figure 4. Proposed network for verification of the algorithm.

6.1. Simulated results to verify algorithm

This section presents the simulation results in MATLAB environment to validate the proposed routing algorithm. In this paper, a model network with 20 nodes has been considered in different terrains (forest, free space, and indoor). The propagation loss and packet loss due to the probability of collision are calculated for all nodes in different terrains. The route obtained using the FBTMPCR algorithm is shown in Figure 5. The best route is: **node1->node16->node3->node12->node9->node15->node20**. On the basis of some performance metrics a comparative study is done for the proposed hybrid protocol (HBA which represents FBTMPCR) with some other existing routing protocol. Figure 6a shows the maximum throughput for this proposed algorithm (HBA) with some other existing protocol like EAMMH, LEACH, and TEEN and it is observed from Figure 6b that the number of dead nodes is much less for this algorithm (HBA). Figure 6c depicts a comparative study of this proposed algorithm with other existing algorithms. It is also found that the transmission delay decreases for this algorithm, which makes transmission faster.

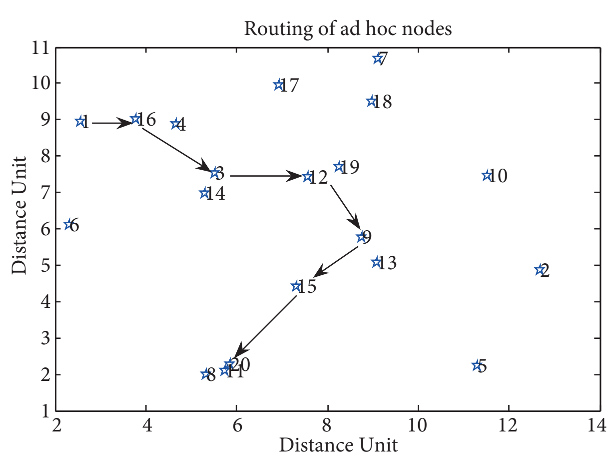

Figure 5. Simulated route of the network.

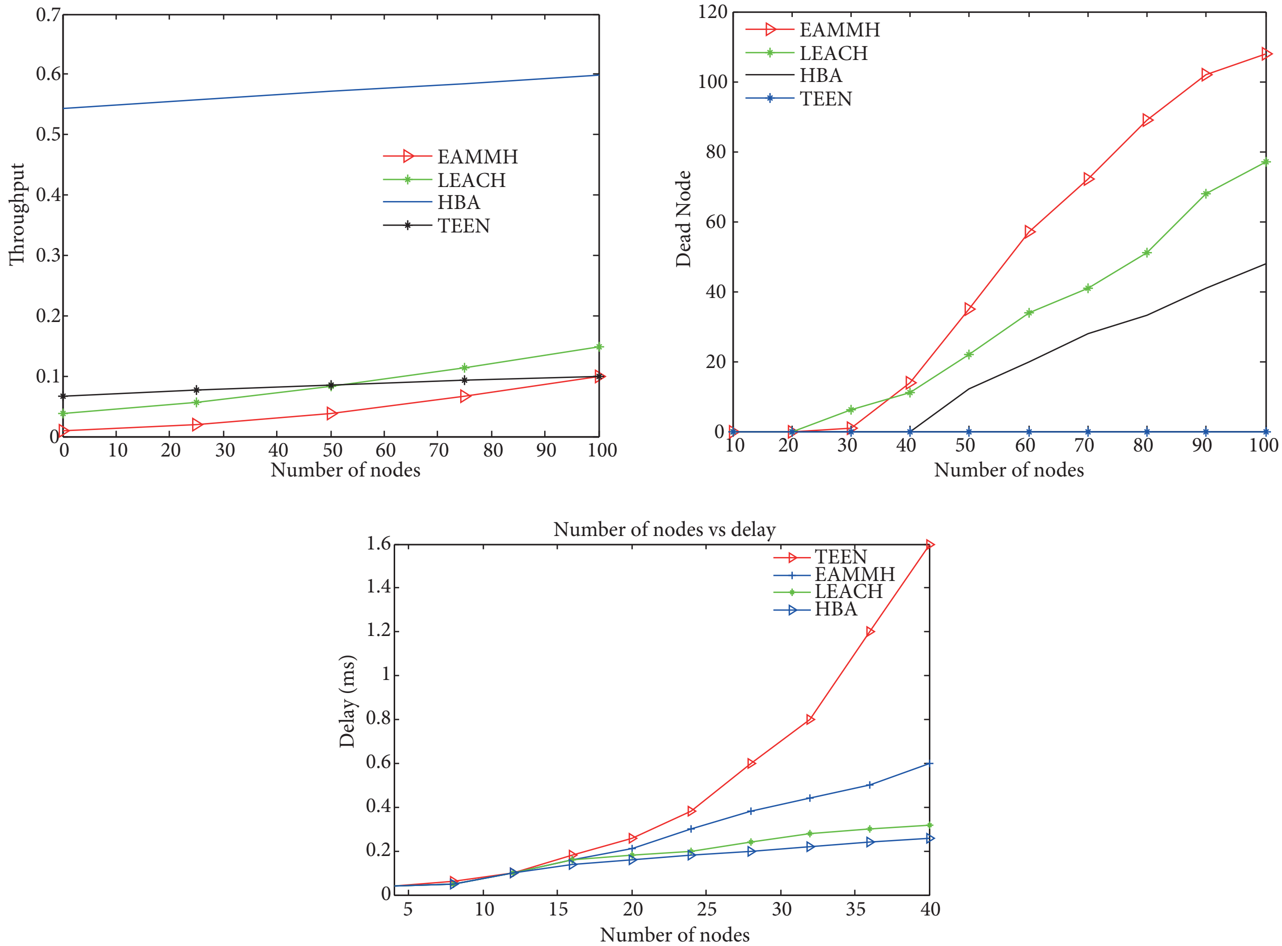

Figure 6. a) Throughput of the network. b) Dead node of the network. c) Nodes vs. transmission delay with different broadcast algorithms.

7. Conclusion

The FBTMPCR algorithm is based on cooperative transmission with the fragmentation technique, where cooperation of transmission is done by selecting the best suitable relay node. Study of the performance of the proposed algorithm provides a higher transmission rate for multihop transmission over direct communication. The communication process of this hybrid algorithm is done in the form of smaller fragments through the properly selected MIMO integrated relay node simultaneously. In this work, we mainly focus on minimizing energy consumption and maximizing network performance. From the performance analysis it may be shown that the proposed algorithm works very efficiently in hybrid terrains. This algorithm shows improvement of the fragment size of packets increases the signal transmission rate and improves the throughput of the network. Transmission delay of the network can also be minimized using this algorithm compared with other existing algorithms. The proposed algorithm outperforms most of the existing algorithms presently in use, which is presented in the simulated results.

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