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RESEARCH ARTICLE

Secure and Energy Savings Communication of Flying Ad Hoc Network for Rescue Operation

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ABSTRACT

The necessity of rapid deployment of military application in complicated terrain without using existing ground-based structured communication system, it requires infrastructure less ad-hoc communication networks mainly Flying Ad Hoc Network (FANET). Infrastructure-based communication system cannot work properly in these situations due to massive destruction and loss of services. Consequently, information exchange becomes one of the major challenges in these circumstances. The transmission mechanism for rescue operation can be done using a hierarchal routing technique that enables any destination node communicate with ground-based server or any other node using intermediate relay nodes within the transmission radius. For rescue operations, rescue team coordinate between ground and FANET using rapidly deployable network with necessary relief efforts. Mobility degree of FANET nodes is much higher and it consists of set of self-configured portable mobile nodes. Hence, lack of congestion control, reliability, and energy consumption all are the main problem of such type of network. To mitigate this problem we develop a minimum energy consume secure routing protocol which makes the communication process secure and energy efficient for rescue operation of FANET.

Key words: Cluster, flying ad hoc network, impulse response, propagation loss, routing

INTRODUCTION

Due to growing demand of future wireless communications systems, the recent research work needs to progress on network architectures and infrastructure deployment procedures so that the network can properly utilize relevant frequency band. To analyze the basic properties of radio channels, the impact of interference in cellular systems is major requirement nowadays. The increasing numbers of wireless devices together can improve bandwidth-consuming applications. In 3rd generation communication system the focus is shifted from mobile telephony to mobile internet access which is actually designed with packet-based air-interfaces.[1] In wireless communication, suitable antennas are used for transmitting particular information. The main challenge of wireless communication system is the unlimited mobility which evolves the concept of mobile communication, for anywhere to any time communication without infrastructure. In the ad hoc architecture, all the nodes in the FANET are flying in nature and can act as a router without central infrastructure. FANET can be rapidly deployed as this type of network doesn't rely on any external support. For these characteristics of FANET, it is major solution for many applications. They can be used as internal communication between communicating nodes. Using this scenario a group of FANET can share and exchange resources and information between each other. FANET can be used as bridge in case of natural disaster or in special scenario in which a communication between two networks is needed when the ordinary communication systems are lacking. This scenario can be temporarily implemented for a particular mission when there is some natural obstacle that prevents installing ordinary network infrastructure. The range of the network can be extended beyond the ordinary distance of Wi-Fi or any other wireless technology. Different routing strategy of ad hoc network is described[2,3] and cluster formation by using flying

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ad hoc node is described in.[4,5] In this article we describe FANET communication for rescue operation. We propose routing algorithm based on the transmission distance and effective energy of the flying nodes in the network. The proposal is as follows: In the first stage, we form a cluster of ad hoc nodes considering effective energy of the nodes. In the second stage, we propose an efficient way of calculating the remaining energy of all nodes in the cluster to save resources. In the third stage, flying ad hoc network (FANET) linked with master server (Data and operation center) using velocity and location of the flying ad hoc nodes.

CLUSTER FORMATION USING FLYING NODES

Here, we consider a model network shown in Figure 1 where five flying nodes (n1, n2…n5) form a cluster according to the basis of distance and energy consumption parameter. Similarly, other nodes form cluster 2. Data operation center or monitoring center on the ground, track the flying nodes for rescue operation via cloud networking. Here, we proposed a new broadcasting algorithm for rescue operation. Now, suppose N number of flying nodes form cluster within a communication coverage range. Let basic coverage range between two flying nodes is L. The presence of multihop operation can extend the coverage range to L_{max}. The multihop can be conducted between at least three nodes. The maximum distance between the first and third one does not exceed $2 \times L_{max}$. That means that the maximum coverage distance in one cluster can be up to $L_{max} \leq (N-1) \times L$ (1)

There are three steps of the communication process is considered for rescue operation. The first scenario is the communication among the cluster members. The second one is the communication between two or more clusters, in case of very large number of flying nodes or when two or more nodes are moving in different directions. The third scenario is the communication between the cluster members and the ground operation center.

ESTIMATION OF REMAINING ENERGY

The energy between the communicating nodes is determined from free-space path loss which in turn represents the attenuation of energy between the feed points of two communicating nodes. Consider all the flying nodes are randomly distributed and for simplicity of calculation consider each node with uniform sensitivity (S). Sensitivity of the nodes is defined as minimum received signal strength to generate sufficient power output in noisy environment. To estimate energy of flying node at the first stage we have to derive propagation loss. The impulse response is a wideband channel characterization and it is required to simulate and analyze the communication channel.[6,7] The channel impulse response is related with the frequency domain transfer function of the channel. Frequency domain transfer function is the Fourier transform of channel impulse response

$F[h(t)]=H(f)$.

Where $H(f)$ the frequency domain transfer function and $h(t)$ is channel impulse response. Thus by taking inverse Fourier transform, impulse response could be directly related to the path loss component of radio transmission. The packet transmission rate of the integrated MIMO FANET depends on the propagation loss or path loss parameter of the network implemented in the heterogeneous terrain. Evaluation of the propagation loss and the selection of the optimal path will improve packet transmission rate, security, and spectral efficiency of the network is analyzed.[8,9] The path loss of MIMO FANET is shown in (2).[10,11]

$$PL = -10\log_{10}\left(\frac{1}{MN}\sum_{f}\sum_{i=1}^{M}\sum_{j=1}^{N}\left|H_{i,j}(f)\right|^{2}\right) \quad (2)$$

where M and N are the number of transmitting and receiving antennas. $|H_{i,j}(f)|$ is the frequency domain transfer function of the channel with transmitting antenna i and receiving antenna j $|H_{i,j}(f)|$ is Fourier transform of channel impulse response H'.

Thus, the frequency domain transfer function (inverse of channel impulse response) is an important parameter to estimate the propagation loss in different terrain. In this section, a special scattering model of MIMO mobile ad hoc network is deployed to determine the impulse response and that is to be used to evaluate path loss. In the subsequent section, an algorithm is discuss to find the minimum loss route out of multiple paths using multipath routing protocol and is shown in Figure 2.

The electro-magnetic wave transmitted from the transmitter is reflected as well as refracted by

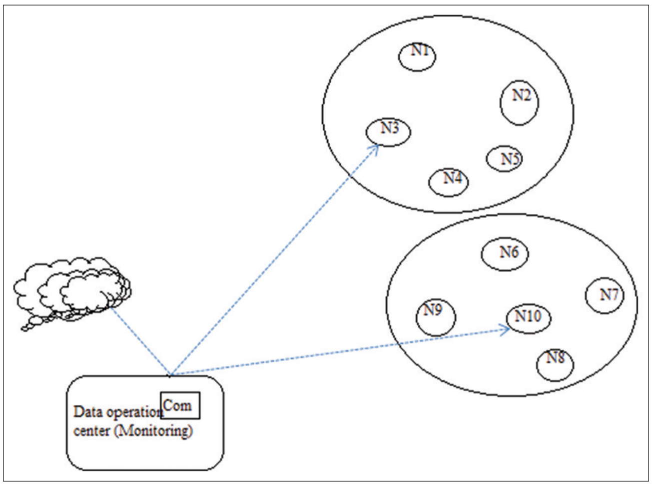

Figure 1: Deployed network for flying ad hoc network communication

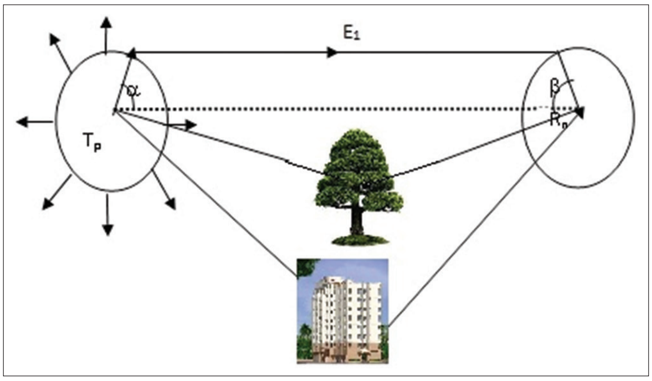

Figure 2: Two ring scattering model

obstacles such as forest, earth surface and building blocks etc. Reflection on the rough surface is called scattering. This process also includes deviation of reflected radiation. In Figure 2 it is shown that two mobile nodes are distributed in the free space terrain and surrounded by the local scattering. The transmitter and receiver ad hoc nodes functions are carried out by mobile nodes and hence surrounded by local scattering. As the transmitting and receiving nodes are both surrounded by scattering, two ring models are considered.[12,13] To estimate the channel impulse response, an EM wave E_1 that follows the path from T_p to R_n of the model network is considered. Let, T_p be the p_{th} antenna element at the transmitter side and R_n be the n_{th} antenna element at receiver, whereas K_1 and K_2 denote scatters which are associated with the transmitter and receiver node respectively. α and β are the effective channel coefficients between p to n^{th} element. The channel impulse response for single channel can be represented as:

$$H_{11} = \frac{1}{\sqrt{K_1 K_2}} \left[\sum_{k=1}^{K_1} \sum_{l=1}^{K_2} \exp \left\{ \begin{array}{l} -\frac{j2\pi}{\lambda}\left(D_{T_p \to S_1(\alpha_k)}\right) \\ +\left(D_{S_1(\alpha_k) \to S_2(\beta_l)}\right) + \\ D_{S_2(\beta_l) \to R_n} \end{array} \right\} + \left\{ j\varphi_1(\alpha_k) + j\varphi_2(\beta_l) \right\} \right] \quad (3)$$

where

$D_{T_p \to S_1(\alpha_k)}$ - Distance between T_p to $S_1(\alpha_k)$

$D_{S_1(\alpha_k) \to S_2(\beta_l)}$ - Distance between $_{S1}(\alpha_k)$ to $s_2(\beta_l)$

$D_{S_2(\beta_l) \to R_n}$ - Distance between $s_2(\beta_l)$ to $R_{n.}$

It is considered that an ad hoc node acting both as a transmitter and a receiver uses multiple antennas. The transmitter node has two antennas whereas the receiver node has three antennas. For each single channel, the impulse response (H_{12},H_{13},H_{21},H_{22},H_{23}) for each antenna is evaluated using two-ring model.

$$H_1 = \begin{bmatrix} H_{11} & H_{12} & H_{13} \\ H_{21} & H_{22} & H_{23} \end{bmatrix}_{2\times 3} \quad (4)$$

A hybrid scattering model which is combination of two-ring model and distributed scattering model are described to evaluate which is the channel impulse response of MIMO based FANET.[14] In this work, combination of two ring channel model and distributed scattering model has been used to evaluate channel impulse response of the integrated network. From the hybrid model the channel impulse response of individual nodes is shows in matrix from and all the nodes can know the channel impulse response. In Figure 3, transmitting node is provided with two antennas and the receiving node is provided with three antennas.

The waves are scattered from each antenna and D_t and Dr be the maximum scattering distance of the transmitting and receiving antennas. Thus, the calculation of MIMO channel impulse response is carried out as given in (5)

$$H_2 = \frac{1}{\sqrt{S}} R^{1/2}_{\theta_r, d_r} G_r R^{1/2}_{\theta_S, 2D_r/S} G_t \left[R^{1/2}_{\theta_t, d_t} \right]^T \quad (5)$$

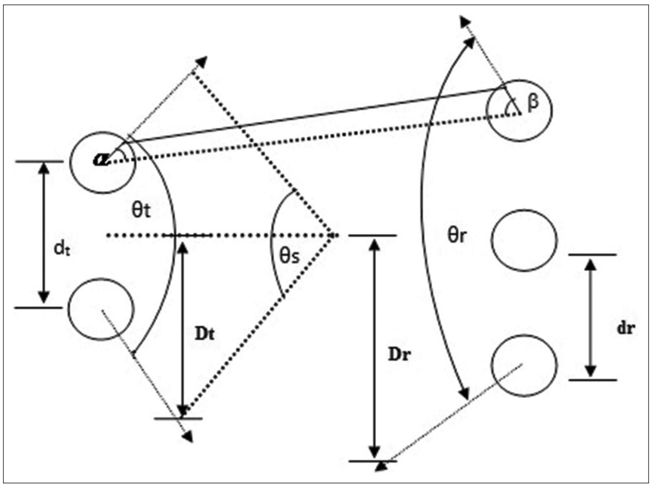

Figure 3: Distributed scattering model

where S - normalized factor. G_t and G_r are random matrices.

$G_t=[]_{S\times 2}$ (6)

$G_r=[]_{3\times S}$ (7)

R_{θ_t,d_t}, $R_{\theta_s,2D_r/S}$, R_{θ_r,d_r} represent correlation matrices

from transmitter, virtual array and receiver, respectively. The correlation matrix for any $(j, k)^{th}$ element can be expressed as[14]]

$$\left[R_{\theta,d}\right]_{j,k}=\frac{1}{S}\sum_{i=-\frac{S-1}{2}}^{\frac{S-1}{2}} e^{-j2\pi(k-j)d\cos\left(\frac{\pi}{2}+\theta_i\right)} \quad (8)$$

θ_i is the AOA (angle of Aperture) of the i^{th} scatter. Here, we consider s^{th} scatter where angle of aperture signify by θ_s. The overall channel impulse matrix will be

$H'=[H_1][H_2]$ (9)

The channel impulse response using two-ring model for M and N number of transmitting and receiving antennas of the MIMO channel is expressed as (10),

$$H_1=\begin{bmatrix} H_{11} & H_{12} & . & . & H_{1N} \\ H_{21} & H_{22} & . & . & H_{2N} \\ . & . & . & . & . \\ . & . & . & . & . \\ H_{M1} & H_{M2} & . & . & H_{MN} \end{bmatrix}_{M*N} \quad (10)$$

Similarly, in MIMO channel the impulse response due to random scattering is given in (11)

$$H_2=\frac{1}{\sqrt{S}}R^{\frac{1}{2}}_{\theta_{nr},d_{nr}}G_r R^{\frac{1}{2}}_{\theta_S,\frac{2D_{nr}}{S}}G_t\left[R^{\frac{1}{2}}_{\theta_{mt},d_{mt}}\right]^T \quad (11)$$

Where $G_t=[]_{S\times M}$ and $G_t=[]_{N\times S}$

The impulse response of the MIMO channel would be

$H'=[H_1][H_2]$ (12)

Thus, the channel impulse response or channel matrix for the MIMO channel where M and N represent the number of transmitting and receiving antennas could be estimated as discussed above. The inverse Fourier transform of channel impulse response is frequency-domain transfer function.

Propagation loss (P_L) for MIMO integrated MANET in combined terrain has already been estimated[14,15] as shown in the following subsection. Let, PL_{1-2} be the forest propagation loss between the communicating nodes where all the nodes consist of multiple antennas, PL_{2-3} be the outdoor propagation loss between two communicating nodes with multiple antennas, PL_{3-4} be the indoor propagation loss, and free space propagation loss combinedly where one node with multiple antennas is situated in outside the building and another one with multiple antennas is inside the building, PL_{4-5} be the indoor propagation loss in same floor between the communicating nodes with multiple antennas and PL_{5-6} is the indoor propagation loss in different floor. Thus, propagation loss models are expressed as

$$PL_{1-2}=-10\log_{10}\left(\frac{1}{MN}\sum_f\sum_{i=1}^{M}\sum_{j=1}^{N}\left\{\left[H_{i,j}\right]^T*\left[I\right]_{N*1}\right\}\times\frac{d^4d_0^2}{R^2f^2}\right) \quad (13)$$

where d is depth of forest in meter, f is frequency of the transmitting signal, R is radius of ad hoc nodes and d_0 is distance between two communicating nodes.,

$$PL_{2-3}=-10\log_{10}\left(\frac{1}{MN}\sum_f\sum_{i=1}^{M}\sum_{j=1}^{N}\left\{\left[H_{i,j}\right]^T*\left[I\right]_{N*1}\right\}*\left(Q*A_r\right)\right) \quad (14)$$

$$\left(Q * A_r\right) = \left(\frac{1}{2}\frac{e^2}{120\pi}\right) * \left(\frac{\lambda^2 g_r}{4\pi l_r}\right) \quad (15)$$

where e - Electric field strength

$$PL_{3-4} = -10\log_{10}\left(\frac{1}{MN}\sum_f \sum_{i=1}^{M}\sum_{j=1}^{N} \begin{matrix}\left\{\left[H_{i,j}\right]^T * \left[I\right]_{N*1}\right\} \\ *\left(Q \times A_r\right)\end{matrix}\right) + \left[-10\log_{10}\left(\frac{1}{MN}\sum_f \sum_{i=1}^{M}\sum_{j=1}^{N} \begin{matrix}\left\{\left[H_{i,j}\right]^T * \left[I\right]_{N*1}\right\} \\ *\left\{L_f F^{K_1} W^{K_2} R\right\}\end{matrix}\right)\right] \quad (16)$$

where F - Floor loss (the value will be 2–3 for same floor),W - Wall loss, R - Reflection loss, K_1 - Number of floor, K_2 - Number of wall

$$PL_{4-5} = -10\log_{10}\left(\frac{1}{MN}\sum_f \sum_{i=1}^{M}\sum_{j=1}^{N} \begin{matrix}\left\{\left[H_{i,j}\right]^T * \left[I\right]_{N*1}\right\} \times \\ \left\{L_f F^{K_1} W^{K_2} R\right\}\end{matrix}\right) \quad (17)$$

$$PL_{5-6} = \left[-10\log_{10}\left(\frac{1}{MN}\sum_f \sum_{i=1}^{M}\sum_{j=1}^{N} \begin{matrix}\left\{\left[H_{i,j}\right]^T * \left[I\right]_{N*1}\right\} \times \\ \left\{L_f F^{K_1} W^{K_2} R\right\}\end{matrix}\right)\right] \quad (18)$$

The effective value of received signal can be estimated by subtracting the propagation loss from transmitted signal. As the flying ad hoc node is battery operated so to increase the stability of the network power awareness of every node is necessary that means each node must calculate its remaining energy and announce it periodically. Energy calculation of all the nodes is done in the physical layer of the network.

In transmission mode, the transmission energy is $E_T \times T$, where E_T is the required energy for transmission and T is the time taken for transmission. In reception, the receiving energy is $E_R \times T$, where E_R is the required energy for reception and T is the time taken for reception operation. The remaining energy of a node is calculated from available energy and consumed energy.

Remaining energy is the subtracted value of consumed energy from available energy.

After calculating the remaining energy, all nodes should announce the remaining energy by broadcasting these values in the network to help the MS to create general idea about the energy level in the network for further actions. After that, all nodes have announced their remaining energy and locations, classification of the nodes role is applied. We pick the nearest node to the distance threshold to serve as a gateway node by which the message is forwarded from one cluster to another cluster. In the other clusters, the nodes are sorted depending on their remaining energy and we select the cluster head which has maximum remaining energy after transmission. The nodes in the network may operate in different modes (transmission mode, reception mode) to preserve the energy in the network. Moreover, provide stability improvements of the network. In transmission mode, the MS or any node transmits signal to other nodes by unicast. In reception mode, the node is act as a recipient of either multicast transmission or a unicast transmission.

PROPOSED MINIMUM ENERGY CONSUME SECURE ROUTING PROTOCOL (MECSRP) ROUTING METHOD

Proposed MECSRP algorithm is presented in this section to for reliable communication. All the flying nodes initiate the communication by broadcasting a message to discover the surrounding nodes. The message contains all the information of the sender node. These pieces of information include the ID number, velocity, location, and direction in degree and communication equipment type. We define a transitional state for smoother operation of cluster formation is called S UNDECIDED. “Undecided” signifies that a node is in condition to search for its host cluster to become a member. Other nodes within the coverage region upon receiving the message will respond by sending a REPLY message. In case of the responding node already presented in a cluster, REPLY message will include its ID number, velocity, location, direction, and the ID number of the swarm. If it is not a member of any cluster it will send FREE message that includes its direction, ID number, velocity, and location. The cluster head finds the nearest nodes using the information of its group and the location of the guest node. The new node will form a temporary network with the nearest neighbor node. The nearest node will work temporarily as relay node to carry the information of the guest node through Cluster Head to the rest of the network. Flowchart

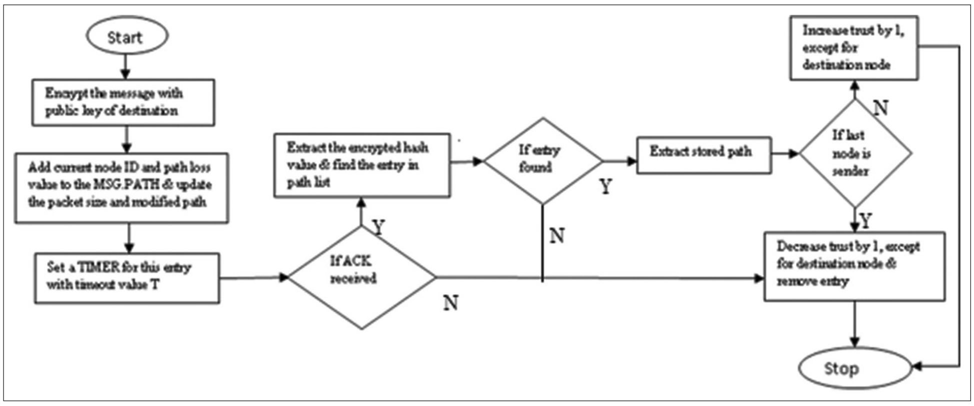

Figure 4: Flowchart of sender node

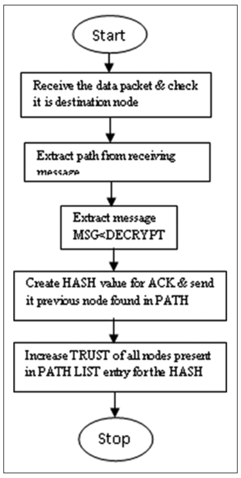

Figure 5: Flowchart of destination node

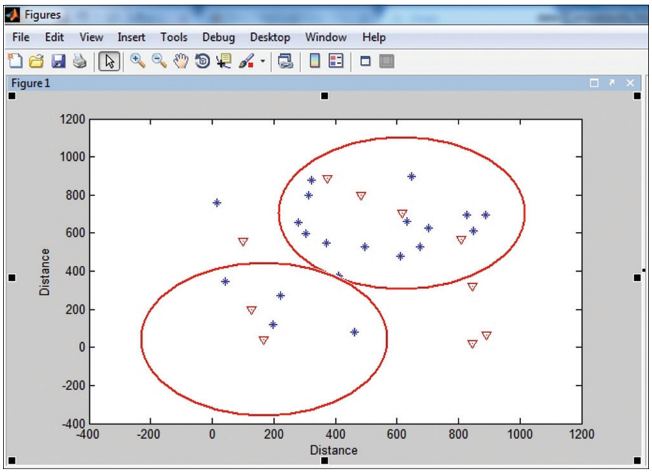

Figure 6: Cluster formation of deployed network

of the function of sender and receiver node is shown in Figures 4 and 5. The simulation result for the cluster formation using this proposed algorithm of the deployed network is shown in Figure 6 considering MATLAB simulation environment). The effective energy of two communicating nodes at different distances is shown in Table 1.

For each stage, two communicating nodes act as a sender node as well as destination node. The operations of two transmitting nodes are as followed:

Table 1: Effective energy obtained in the different propagation environment

Propagation Loss environment	Distance between two communicating nodes	Effective received signal power (mW)
Forest +Outdoor	30	3.336
Forest +Outdoor	60	5.925
Forest +Outdoor	70	7.035
Forest	70	72.591
Forest	60	53.334
Forest +Outdoor	50	5.268
Outdoor	40	6.396
Outdoor	60	10.371
Outdoor+Forest	50	22.311
Outdoor+Forest	60	26.308
Outdoor	50	7.962

Function of sender node

Step 1: Set the parameters for different terrain and initialize the number of antennas.

Step 2: Calculate H matrix and determine Propagation Loss (PL).

Step 3: Initiate routing algorithm and update data table for each node

Step 4: Input the number of nodes, propagation loss between any two nodes, and metric (number of hops) of all the nodes of the network. Initially set Flag (F=1) for all nodes.

Step 5: Initialize a variable (v) with propagation loss between the first two nodes

Step 6: Compare all propagation loss with v and select the node with minimum energy for transmission

Step 7: On basis of minimum distance and Minimum energy consumes the clusters are formed

Step 8: The message is transmitted from ground station to cluster head via cloud computing.

Step 9: Message is encrypted
ENC-MSG ← ENCRYPT (MSG)
Step 10: Add current node ID, path loss value to the MSG.PATH and remaining energy of each node to NODE.ENG
Step 11: Estimate HASH VALUE of ENC-MSG:
Step 12: Create a table using entry for PATHLIST: Data<HASH-VAL, PATH LOSS VALUE, NEXT-HOP-ID >NSG.PATH
Step 13: Forward data to the next hop by selecting minimum value energy consumed nodes as mentioned in the routing and wait for ACK within the transmission period.
Step 14: If ACK of transmitted packet is received within the time period then encrypted hash value is extracted.
HASHVAL-R<-ACK.ENC-HASH
Step 15: Extract minimum energy consumed node value Entry-PATH<-NODE.ENG.
Step 16: If the ACK is received by the last node in Entry-Path then the sender node id is increased by 1, except for the destination node.
Step 17: Stop.

Function of destination node

Step 1: Receive the data packet and check whether it is intended.
Step 2: Extract the value of the minimum energy consumed node path from the receiving message.
PATH ←MSG.PATH
Step 3: Decrypt and extract the received message
REC-MSG←DECRYPT (MSG.ENC-MSG)
Step 4: For ACK message hash value is created HASHVAL-C←HASH (NODE.ENG)
Step 5: SIGN←ENCRYPT (HASHVAL-PVT-KEY-DEST)
Step 6: To find route transmit the ACK message to parent node Step7: Stop.

CONCLUSION

In this proposed work, evaluation of channel impulse response has been carried out to estimate the propagation loss of the ad hoc network with multiple number of antennas in different environment such as outdoor, forest, or combined propagation environment. A new algorithm (MECSRP) is proposed here which is implemented to find out a minimum energy consumed route for reliable communication of FANET. High overhead cost operation of collision during transmission time are main limitation of this type of network. In future we want to implement multilevel hierarchical routing and time-slotted on demand routing to minimize all the limitations.

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