A Hybrid Wireless Network Model for Post Disaster Relief Operations

SK Dwivedi, NK Shukla, Sudhakar Pandey

Abstract— ***In the event of large scale natural disaster, most of the public utility services like communication, power and roads get disrupted. Post disaster relief operations need quick but reliable restoration of these services. Rapid and reliable deployment of communication setup is highly crucial to commence rescue and relief operations. Mobile Ad-hoc Networks (MANETs) can be built quickly but suffer from problems due to nodes mobility; on the other hand, Static Ad-hoc Networks (SANETs) can provide better performance but takes longer time to establish. This paper presents a Hybrid Network model having features like scalability, robustness, speedy deployment, portability, cost effective and desired QoS. The proposed Hybrid Ad-hoc Network (HANET) topology is a combination of static nodes of grid topology of SANET and the mobile nodes of random topology of MANET. In the recent past, many researchers have shown interest in the development of directional antenna based MAC protocols. Although directional antenna brings in advantages of higher transmission range, spatial reuse and so on but equally suffers from typical problems of hidden/exposed terminals, head-of-line blocking and deafness etc. In this paper, we have proposed a novel protocol based on the directional smart antenna to exploit the advantage of spatial reuse in terms of multiple concurrent transmissions while ensuring collision avoidance. Simulation results demonstrated that the throughput and end-to-end delay performances of the proposed MAC protocol with HANET model is significantly better than the legacy MANETs with IEEE 802.11-MAC.***

Keywords: MANETs) can be built quickly but suffer from problems due to nodes mobility;

I. INTRODUCTION

Rapid deployment of a reliable communication network is one of the crucial requirements of any disaster relief operations. The reliability of communication network which is to be used to communicate among responders and with relief headquarters for control and command or used by the victims of the emergency situations, is one of the critical requirements [1] [2]. During disaster relief operations, Multi-hop Wireless Network (MWN) [3], [4] can play an important role in rapid and cost effective deployment of communication services. In any MWN, data is routed toward the destination through several intermediate nodes (routers) unlike single hop wireless networks wherein data is transmitted over only one hop. MWNs are scalable, adaptable and dynamically self-organizing.

Manuscript Details: Revised on January 03, 2012

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Depending on their primary objectives, MWNs can be classified into Mobile Ad-hoc Networks (MANETs), Mesh Networks, and Sensor Networks. MANETs face a challenge called problem of network partition. In a MANET, whenever a mobile node moves away from the network, it results into breaking of existing network into two isolated part called as *network partitioning*. Due to this, the end-to-end connectivity is disturbed and packets are dropped resulting into severe degradation of aggregate throughput. Since the MAC layer cannot distinguish whether the packet losses are due to collision or unreachable next hop, therefore, when packets are dropped, it reports false link/ route failures leading to time consuming route search or re-routing procedures, thereby increasing end-to-end delay.

In this paper, we have proposed a hybrid architecture of MANET and SANET called as Hybrid Ad-Hoc Network (HANET) model wherein all the static nodes act as routers for the mobile nodes. Also, by adding static nodes, the coverage area, reliability and connectivity of the network are enhanced. IEEE 802.11 technology is used to set up the wireless links among the network nodes. Traditionally, IEEE 802.11 suffers from the problems of poor spatial reuse. This has been addressed by introducing a novel directional antenna based MAC protocol, namely SBSAA-MAC. The proposed SBSAA-MAC protocol reduces the medium contention through concurrent scheduling of multiple transmissions. Finally, the aggregate throughput and end-to-end delay performance of the proposed HANET model with the proposed SBSAA-MAC protocol has been evaluated and compared with the legacy IEEE 802.11 based MANET/SANET system using simulation techniques.

II. PROPOSED MAC PROTOCOL FOR MOBILE AD-HOC NETWORKS

In recent years, for multi-hop MANETs, several MAC protocols based on multiple beam antennae have been proposed [5], [6], [7], [8], [9]. We propose a novel MAC protocol, namely Stack Beam Smart Antenna Array MAC (SBSAA-MAC) protocol for wireless networks.

The Proposed SBSAA-MAC Protocol

The proposed SBSAA-MAC protocol is an asynchronous and adaptive media access control protocol, which works on the single channel and single transmission power architecture. The proposed MAC protocol is based on IEEE 802.11 DCF scheme but also works well in multi-hop scenarios. The protocol is based on IEEE 802.11 standards and therefore works on contention-based CSMA/CA.

Published By:
Blue Eyes Intelligence Engineering
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The key features of the protocol that helps in concurrent transmission are as follows:-

(a) An additional Control Gap (ACG) is inserted between the successful exchange of RTS/CTS and transmission of DATA packet so as to provide an opportunity to the neighbouring nodes for exchange of their own RTS/CTS and schedule concurrent data transmission.

(b) Collision avoidance information is provided in the control frames (RTS/CTS) which can be used by the neighbouring nodes to determine the possibility of scheduling their transmission.

(c) Concurrent transmissions by the neighbouring nodes is a locally controlled process and therefore asynchronous.

In SBSAA-MAC, each node maintains a data structure called Active Neighbour List (ANL), to record this information. Let us take three neighbouring nodes a, b and c. Out of these, a and b are involved in active transmission while c is overhearing their control packets. Then, for every active node *b* in the vicinity of node *c*, the ANL_c has the following information:

$\{B_{address}, G_{ab}, T_{data}^{(ab)}, T_{ack}^{(ab)}, X\}$

Where:

$B_{address}$ is the address of the active node *b*.

G_{ab} is the estimated channel gain between nodes *a* and *b* and is computed as

$G_{ab} = P_{rx}^{(b)}/P_{tx}$, where $P_{rx}^{(b)}$ is the signal power of the received control packet of node *b*, and P_{tx} is the single transmission power (common to all nodes).

$T_{data}^{(ab)}$ and $T_{ack}^{(ab)}$ are the starting times of the DATA and ACK packets of the transmission between nodes *a* and *b*. $T_{data}^{(ab)}$, $T_{ack}^{(ab)}$ are relative time included in the control packets and give an idea about the remaining duration from the current time. *X* is a single bit tag used to differentiate between the transmitter and receiver. It is set to 1 if the control packet is received from a transmitter and is set to 0 if the control packet is received from a receiver.

Antenna Model

The SBSAA-MAC protocol uses directional antenna to enhance the throughput performance of the network. It is assumed that each node is equipped with a radio trans-receiver and a Stack Beam Smart Antenna Array [7], which is capable of determining the exact Angle of Arrival (AoA) of an incoming packet [10]. Each SBSAA with Y elements can form Y non-overlapping zones each spanning over an angle of 360/Y degrees. Beam shape is assumed to be conical with no side-lobe interferences [7] and complete attenuation of the transmitted signal outside the beam pattern. Directional range is considered constant and equal to the omnidirectional range. The total antenna power (P_{TOTAL}) is uniformly divided among Y beams as P_{TOTAL}/Y. A directional beam is formed by applying a complex weight vector to a received vector, which is a set of multiple signals received at different elements of the antenna array [11]. This is used to find the exact AoA.

Concurrent Transmission Scheduling using SBSAA-MAC Protocol

The SBSAA-MAC protocol allows better spatial reuse by scheduling two or more concurrent transmissions as depicted in Fig. 1.

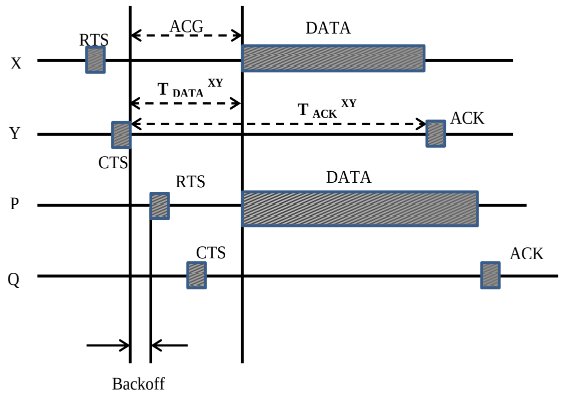

Fig. 1: Scheduling of Concurrent Transmissions X→Y and P→Q

Node X first transmits an RTS packet comprising scheduled start time of DATA/ACK i.e. T_{data}^{XY} / T_{ack}^{YX}. RTS packet is transmitted from all the antenna elements of node X. The synchronized clock is not required as T_{data} and T_{ack} are specified relative to the receiving time of the associated control packet. On receipt of RTS, node Y records the direction of node X. Now, node Y responds with a CTS packet containing similar timing information to node X on all of its antenna elements. On receipt of CTS packet, node X records the direction of node Y. After the successful exchange of RTS/CTS packets, node X awaits for the period specified by ACG before commencing transmission of DATA packet. During this ACG period, neighbouring nodes P and Q can exchange their control packets and schedule their transmission. If the transmission between nodes P and Q is successfully scheduled, then on expiry of ACG period, the simultaneous X-Y and P-Q transmissions commence. During the ACG period, if more than one neighbouring nodes attempts to access the channel then contention based CSMA/CA method of IEEE 802.11 is employed. ACG is composed of an adjustable number of Access Slots (AS). An AS period is fixed and is equal to the sum of the time required to transmit RTS, CTS and maximum back-off period when the contention window (CW) is equal to 31. The ACG period is just sufficient to exchange the control packets and schedule one potential secondary transmission..

Active Neighbour List (ANL) is the key to concurrent transmission. A node updates its ANL, if it receives control packets intended for other nodes. On receipt of control packets, the node extracts the information contained in the control packet and makes an entry in its ANL. Subsequently, on receipt of ACK packet after a successful transmission, the transmitter/receiver nodes will delete all the entries in ANL indicating the end of the current transmission.

For other neighbouring nodes not participating in the transmission, the ANL entries will be deleted on receiving a DATA/ ACK packet that belongs to other transmission in vicinity.

III. THE PROPOSED HYBRID NETWORK MODEL

In the proposed Hybrid Network architecture, each AP is connected to Central Control Unit for assistance to the disaster victims or the rescue task force. Also, these APs are connected to mobile stations through wireless links forming a basic service set. Because of range limitations of APs, mobile nodes falling outside the transmission range of AP may not get web-based services/ INTERNET services/ command control link. These mobile nodes may form MANET but will not be able to get connectivity with the Central Control Unit. Further, due to partitioning problems, the MANET nodes may lose the connectivity among themselves. Therefore, in order to address these issues, proposed Hybrid Ad-hoc Network (HANET) model includes static nodes in a grid of M×N thereby forming a Static Ad-hoc Network (SANET) which supports mobile nodes falling outside the transmission range of the AP. This SANET grid structure is connected to the AP for INTERNET/ Central Control Unit through a chain of fixed nodes where the last static node of the chain is within the transmission range of the AP. This ensures that the MANET nodes are connected to some Central Control Unit for any emergency situations.

Static nodes in the SANET of the proposed Hybrid Network architecture are placed at regular interval of 250 meters in a two dimensional regular grid so as to maintain the desired connectivity and therefore ensuring maximum throughput and QoS. The network can be expanded to increase the coverage area by adding new static nodes at the predetermined locations. It is assumed that SANET nodes do not have their own data to transmit and therefore act as routers for forwarding the packets.

Each node in this proposed Hybrid Network Model is equipped with stack beam smart antenna arrays and uses SBSAA-MAC protocol. In the grid topology of the SANET, each node is surrounded with four immediate neighbours and therefore the number of beams each antenna can have is also four. However, mobile nodes of the MANET may form more than four beams in their antenna. The mobile nodes can communicate with other nodes directly, if they are one hop away. However, in a multi-hop scenario, each mobile node uses static nodes of the SANET as intermediate nodes to forward their packets to the destination node. As each node in the SANET has four neighbouring nodes, it has four routes options for forwarding a packet. Therefore, in the proposed Hybrid Network Model using SBSAA-MAC protocol, concurrent transmissions can be scheduled within the interfering region easily thereby improving aggregate network throughput.

IV. PERFORMANCE EVALUATION AND SIMULATION RESULTS

Parameters used in the simulation are based on IEEE 802.11 standards and are as follows:-

Transmission Range	:	250m
Carrier Sensing Range	:	550m
Propagation Model	:	Two Ray Ground
Packet pay load	:	1500 Bytes
TCP header/ ACK size	:	20/14 Bytes
Channel Bit Rate	:	2 Mbps
SIFS/DIFS	:	10/50 μs
CW_{min} & CW_{max}	:	32/1024

For simulation, it is ensured that all the HANET nodes are running with saturated load levels. Also, since the network topology is finite, the boundary nodes transmit at a higher rate than the nodes at the centre. Poisson process with equal mean arrival time is used to generate the packets. In simulation, five end-to-end flows have been considered. Single hop flow gives maximum throughput as compared to multi-hop connection (without concurrent transmissions). In two-hop flow, concurrent transmissions are not possible as a receiver cannot transmit while receiving other transmissions. Therefore, for simulation, two cases are considered, firstly each flow with 3-hops and then each flow with 5-hops. In each case, the throughput and end-to-end delay performance of proposed HANET topology is compared with the MANET random topology. Also, the throughput and end-to-end delay performance of proposed HANET topology is compared between IEEE 802.11-MAC and SBSAA-MAC schemes.

Comparative Performance Evaluation between MANET Random Topology and Proposed HANET Topology using IEEE 802.11-MAC (Three Hops Case)

In the first scenario, MANET random topology with IEEE 802.11-MAC and HANET with IEEE 802.11-MAC are considered where all the five flows are of 3 hops. In this scenario, concurrent transmissions are not possible in 3 hops due to the use of legacy IEEE 802.11-MAC. Further, due to the mobility of nodes, individual flow throughputs depend upon the location and the direction of motion of a node participating in the communication.

The simulation results of flow-wise throughput performance are shown in Fig. 2. Flow-wise throughput performance of HANET is significantly higher than the MANET due to better End-to-End connectivity through static nodes. The aggregate throughput performance of the scenario is given in Fig. 3. Here, the MANET throughput is slightly higher than that of HANET because in hybrid case due to higher RTS/CTS contentions, throughput suffers slightly. Similarly, the end-to-end delay performance is presented in the Fig. 4, wherein, the performance of MANET is slightly better than that of HANET due to the same reason of excessive RTS/CTS contentions.

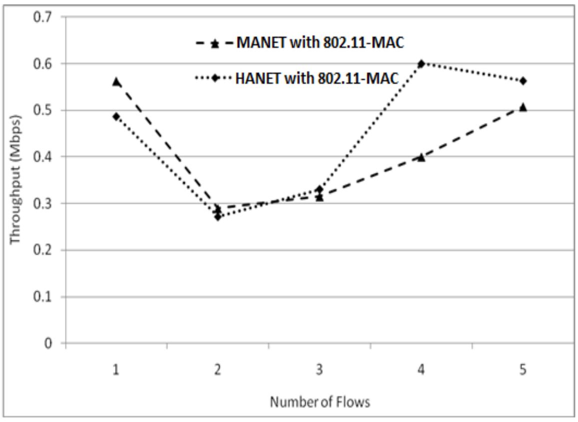

Fig.2: Flow-wise Throughput Performance under 802.11-MAC MANET versus HANET (3-Hops Case)

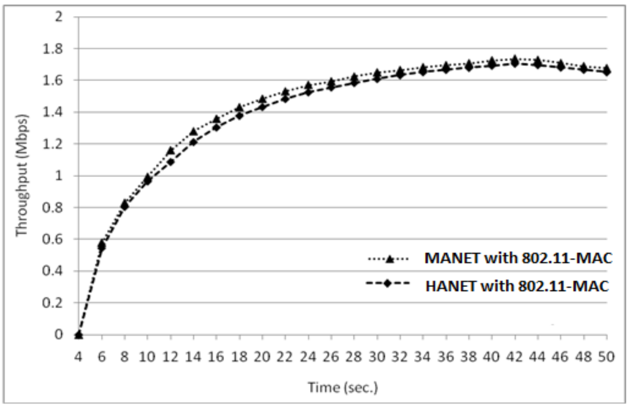

Fig. 3: Aggregate Throughput Performance under 802.11-MAC MANET versus HANET (3-Hops Case)

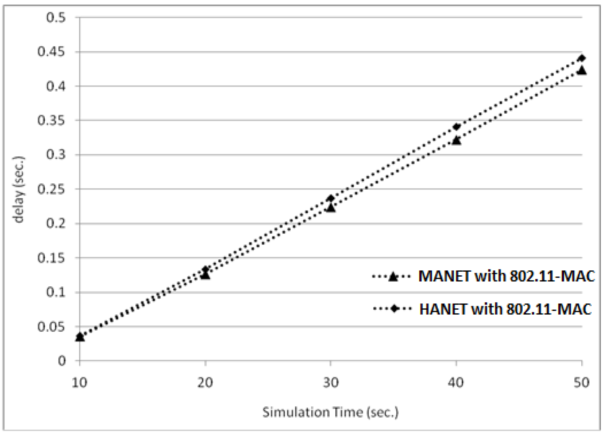

Fig. 4: End-to-End Delay Performance under 802.11-MAC
MANET versus HANET (3-Hops Case)

Comparative Performance Evaluation between MANET Random Topology with IEEE 802.11-MAC & Proposed HANET Topology with SBSAA-MAC (Five Hops Case)

In this scenario, MANET random topology with IEEE 802.11-MAC and HANET with SBSAA-MAC are considered wherein all the five flows are of 5 hops. The flow-wise throughput performance is presented in Fig. 5. Due to the increased number of hops together with concurrent scheduling of transmissions available with SBSAA-MAC, the proposed HANET outperforms corresponding MANET with IEEE 802.11-MAC. Another reason of poor performance of MANET is frequent route failures which do not occur with HANET because of the availability of SANET grid nodes. Further, as shown in Fig. 6, due to multiple scheduling of concurrent transmissions, the aggregate throughput performance of HANET with SBSAA-MAC is far better in comparison to MANET with IEEE 802.11-MAC. On similar grounds, as shown in Fig. 7, the end-to-end delay performance of HANET with SBSAA-MAC is better than that of MANET with IEEE 802.11-MAC.

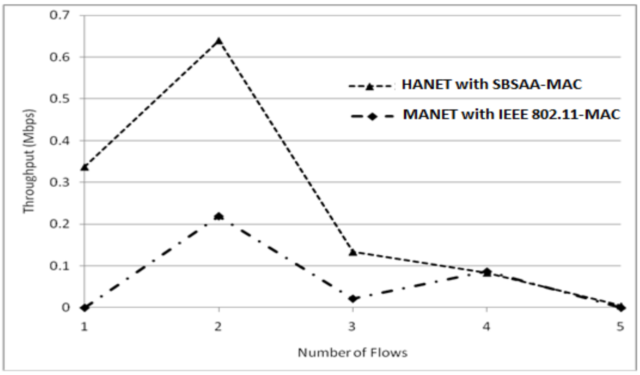

Fig. 5: Flow-wise Throughput Performance of MANET with 802.11-MAC versus HANET with SBSAA-MAC (5-Hops Case)

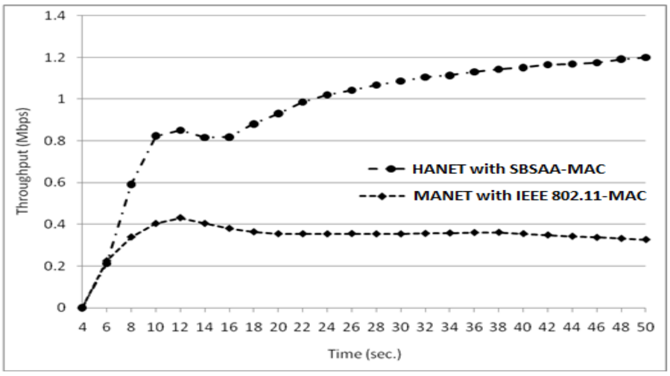

Fig. 6: Aggregate Throughput Performance of MANET with 802.11-MAC versus HANET with SBSAA-MAC (5-Hops Case)

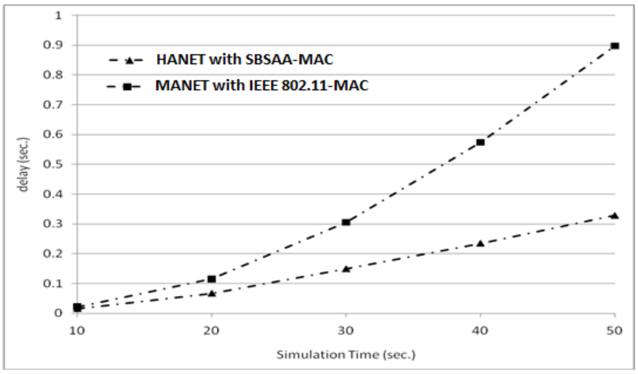

Fig. 7: End-to-End Delay Performance of MANET with 802.11-MAC versus HANET with SBSAA-MAC (5-hops Case)

V. CONCLUSION

In critical situations, like disaster relief operations, rapid and reliable deployment of communication setup is very important. The communication setup with centralized command and control post is the priority requirement for disaster victims and relief task force. Legacy MANET can be deployed quickly but suffers from the network partition problem leading to frequent route failures. Also, due to node mobility only some of the MANET nodes are in the transmission range of an AP whereas other nodes that are out of range of AP, are unable to communicate with the central command.

The proposed HANET Network Model is based on hybrid topology which includes fixed grid of SANET nodes and mobile nodes of MANET. The mobile nodes of HANET are connected to AP through chain of fixed nodes of SANET and therefore can cover the entire region of disaster with required reliability and QoS. Also, the proposed HANET is highly flexible and can be extended by adding static nodes.

IEEE 802.11 MAC protocol restricts concurrent transmissions within the interfering regions of four hops distance between two simultaneously transmitting nodes. In this paper, a novel Stack Beam Smart Antenna Array based MAC protocol called as SBSAA-MAC has been proposed. The proposed SBSBAA-MAC protocol is based on spatial reuse and therefore allows concurrent scheduling of multiple transmissions within the interfering range of a node.

The simulation results have demonstrated that the proposed Hybrid Network Model (HANET topology) along with proposed SBSAA-MAC protocol, outperforms MANET with legacy IEEE 802.11-MAC protocol. Also, with longer transmission paths, in terms of number of hops, more concurrent transmissions can be scheduled to further improve the performance of the network. The proposed HANET is capable to provide desired QoS and therefore can be implemented for Internet access in remote and rural areas as the traffic load in these area is of low to moderate value. The proposed HANET can also be deployed in urban areas to address small scale emergency situations. The proposed HANET provides better results, if the area of operations is limited and the density of traffic generating mobile nodes is low.

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