BeMAP: BANDWIDTH EFFICIENT MEDIUM ACCESS PROTOCOL FOR TACTICAL MANET WAVEFORMS

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Abstract-MANET is a promising networking technology for tactical network. The behavioural characteristics of MANET like self-forming/healing and bandwidth efficiency mainly depends on the design of underlying MAC protocol. The protocol also plays an important role to meet the dynamics of tactical environment which is characterized by arbitrary and dynamic node topologies along with continuously changing traffic pattern This makes mobile wireless communication complicated and difficult to maintain connectivity. A distributed and dynamic TDMA channel access protocol can manage outgoing traffic based on network degree and traffic type. In this paper a new Bandwidth efficient Medium Access protocol (BeMAP) is proposed. The protocol is based on theidea of applying dynamic control cycle which is adaptive to the current network degree, thus optimally utilizing control slot bandwidth. We also present the use traffic slots for three kinds of slot allocation procedure to effectively utilize data bandwidth that suits various traffic characteristics.

Keywords: Tactical network, MANET, MAC, Dynamic TDMA, Adaptive Control Cycle

INTRODUCTION

An import aspect of mobile ad hoc networks is medium access control (MAC). The medium access protocol is needed to provide efficient and fair sharing of the radio channel resources. A proper design not only guarantees successful information exchanges among nodes in the presence of conflict but also maximizes throughput. The tactical mobile networks are required to operate in heterogeneous environments with varying bandwidth-delay characteristics. Scheduled MAC protocols, such as TDMA, are potentially better suited to networks with heavy or unbalanced load [1]. The TDMA MAC also suits tactical MANET environment because of its capability to support QOS, which is not guaranteed in contention protocols [2].

In static TDMA schemes the node's time slot gets wasted when it does not have traffic to transmit. That's why a mechanism that conserves the channel bandwidth is needed in such scenarios. Moreover in a fully connected network, it comes natural that the channel bandwidth is evenly shared among all nodes using a suitable MAC protocols; because the priorities of nodes or links are uniformly distributed. However, in tactical ad hoc network where nodes are randomly placed over an irregular plane, bandwidth allocation to a node is much more complex. In such scenarios the dynamic TDMA gives better performance. These protocols divide the channel into control slots and data slots. The data slots are dynamically allocated to a node based on traffic needs and priority. The protocols also exploit spatial reuse of the radio channel to enhance the channel bandwidth efficiency.

The recent advances in hardware and wireless communication technologies have led to an increasing interest in internet like multimedia service on tactical network. However, unlike the wired network where bandwidth is usually abundant, in MANET the bandwidth is always scarce. Therefore we need a mechanism at medium access layer which maximizes the use of channel bandwidth for application traffic. In this paper we are proposing a medium access protocol which maximizes slot bandwidth utilization for user traffic by adapting to autonomous behaviors of mobile hosts like new node joining, node leaving, dynamic resource reservation for stream traffic etc. The remaining paper is organized as follows. Section II summarizes previously done related work. In section III, the proposed protocol is presented followed by conclusion in. Section IV.

RELATED WORK

In USAP [2] and USAP-MA [4], TDMA slot assignment protocols for ad hoc networks were proposed. The USAP protocol provides basic idea of dynamic slot assignment of data slots. The USAP-MA is an extension of USAP which introduces ABC (Adaptive Broadcast Cycle) to change the frame length and the frame cycle dynamically depending on the number of mobile hosts and the network topology. USAP-MA improves the channel utilization. However, USAP-MA does not offer neither when and how to change the frame length nor how to select a slot assigned to a new node. Moreover, in this protocol no change in control slots number is possible within a frame. Therefore unassigned slots appear in the latter part of the frame which leads to underutilization of channel bandwidth.

In [5] a TDMA slot assignment protocol was proposed to improve the channel utilization, which controls the excessive increase of unassigned slots by changing the frame length dynamically. This enlargement of frame size means increase in frame cycle. In tactical environment there are many applications [4] which have strict latency requirements and the enlargement of frame cycle could lead to service delay for a particular service beyond its QoS requirement. Moreover, this work doesn't provide all the necessary details to arrive at a real world implementation and mechanism to reduce the frame length when a node leaves the network.

In [6] slot reservation scheme based on NAMA and contention access is proposed. In this work authors proposed two types of control slots which are network entry and control slots. In this scheme the new node has to contend with existing network nodes to join the network, which makes joining time is dependent of existing network degree. Since the resource reservation for a particular service is indirectly depends on contention access. Therefore this protocol cannot assure QoS for critical tactical services.

The Tactical networks, those are characterized by dynamic node topologies and continuously changing traffic pattern, making mobile wireless communication complicated and difficult to maintain. The existing MAC designs don't fully explain that, at given time how it can effectively utilize the control slot bandwidth if there are less no of nodes then the network size. This is very common in mobile scenarios.

PROPOSED MAC APPROACH

A distributed and bandwidth efficient TDMA channel access protocol can manage outgoing traffic based on network degree and traffic type. It can also maintain latency and data rate requirements keeping the control overhead minimum. In BeMAP, we are proposing dynamic NCS cycle adaptive to the current network degree which optimally utilizes the control slot bandwidth. We also present the use of three kind of slot allocation procedure in data slots to effectively utilize data bandwidth that suits various traffic characteristics.

Frame Structure:

In BeMAP, the network time is divided in TDMA frames, each containing a fixed number of time slots. Therefore the cycle duration is fixed. It is assumed that entire network is synchronized on frame and slot basis. Each frame is divided into two phases, namely, the control phase and the data phase, as shown in Fig. 1. The size of each slot in the control phase is expected to be smaller than the one in the data phase to increase throughput efficiency; however it can vary from one implementation to another. Without loss of generality we have assumed all slots are of the same size. The control phase is used to perform all the network control functions, such as frame synchronization, power management, code assignment, VC setup, slots request, routing management, etc.

BeMAP recognizes the importance of network maintenance and provides specific bandwidth provision for the delivery of network control messages. These messages include topology control messages, route creation and maintenance messages, and network entry messages. Most of the message data structures are created using bitmaps to minimize the overhead. The other overhead is also carefully controlled so that network performance is not heavily affected by MAC protocol management data.

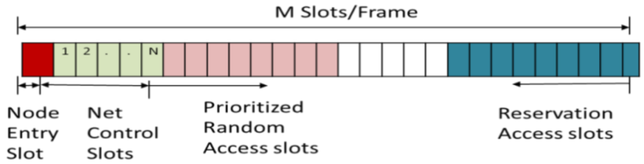

Figure 1: BeMAP TDMA Cycle

The control phase of TDMA Cycle consists of NES and NCS , while data slots are arranged in PRAS and RAS to meet various objectives of MAC protocol. The slot's functional needs are as follows.

a) ***Node Entry Slot (NES):*** This slot is used by a new node to send its net joining control information to existing network nodes. In case of more than one node trying to join network at the same time, S-Aloha with backoff algorithm is used for contention resolution among new node for accessing NES. Traffic across these slots uses NCS control information to reduce probability of collision.

b) ***Net Control Slots (NCS):*** These slots are occupied by each node in the two hop neighbourhood to exchange their network control information. Periodic transmission of Network Control Frames (NCF) in NCS enables node discovery, supports dynamic network organization, and hence provides support for mobility. NCS also provides basic timing for network synchronisation and to carry out negotiation for reservation and scheduling information for accessing the medium.

c) ***Reservation Access slots (RAS):*** These slots are used by the nodes to transmit their real-time traffic data using hard scheduling over virtual circuits (VC). Slots reservation negotiation takes place beforehand in NCS. The amount of data slots/frame assigned to a VC is determined according to a QoS (bandwidth) requirement. These slots are arranged towards the right side of the frame**.**

d) ***Prioritized Random Access Slots (PRAS):*** These are the slots that are remaining in the TDMA cycle excluding NES, NCS and RAS. These slots are used for contention based channel access as well as for soft reservation (SR). Under soft reservation come the services which require end to end connection but does not essentially need a pipe of specific data rate. The example includes tactical chat. Rest of the other datagram services are scheduled based on priority and Source MAC ID to meet best effort QoS.

Traffic Slot Scheduling:

To meet the operational requirements of tactical forces a variety of data services are required to be supported by the networking waveforms. Each service should cater for the specific need of the user and must be optimized for the required QoS. Broadly communication services can be divided into voice and data. To meet the various operation needs of user/waveform, we have categorized traffic types in to six catogries as shown in table 1. These traffic types in nature are generic wrt technical description to meet QOS. Various scenario specific user services can be put under these sample traffic categories.In this section we explain how BeMAP handles these traffic types. However this does not restrict its ability to handle other message types.

Table: 1: Traffic Type Classification

Sr#	Traffic type	Services	Scheduled in
1.	***High data rate Streaming data***	Video streams, voice, high rate data streams	RAS
2.	***Low data rate stream***	Tactical chat, status reporting	PRAS/SR
3.	***Burst messages***	Small, unscheduled bursts of data	PRAS
4.	***Short Periodic messages***	Network maintenance and control messages	NCS
5.	***Time Critical tactical messages***	Small, unscheduled but time sensitive command and control(C2), SA	NCS
6.	***Multicast and broadcast Messages***	Low rate Stream/ data, Group/ Net call	NCS/PRAS

Under first category of 'High data rate streaming data' comes the services that require real time performance with high bandwidth demand from the channel. In such services re transmissions are not done due to their real time nature. Therefore ACK/ARQ mechanism is not required at MAC level. These services are setup between users for relatively long time wrt TDMA frame duration. BeMAP schedules such services in RAS slots after successful setup of VC between end nodes.

Small, unscheduled bursts of data are transmitted in PRAS where node contends for slot using NAMA[14]based prioritized access algorithm. In this access scheme each node has a common priority table for each service supported by the waveform. Based on this priority and NAMA hash function, a single winner for the PRAS is decided among two hop contending nodes. In tactical scenario sometimes it is also required to assign transmission priority based on node ID instead of traffic type (For example commander should get transmission priority over soldier). The BeMAP contention access priority policy can also be configured as per mission requirements at the time of deployment.

The 'Low data rate stream' category includes services like tactical chat or status reporting. These services require end to end connection along with low packet delay. There could be long pause period between two consecutive traffic packets. Static allocation of slots during entire connection time does not utilize bandwidth efficiently; therefore BeMAP handles such services under soft reservation and schedules them in PRAS. In soft reservation, slots are reserved for communicating nodes. However if the sender doesn't have any data to send in current cycle, the slot becomes available for prioritized random access.

In 'Short Periodic message' category comes the traffic type which are periodic but are of short duration. This traffic types also includes messages that are important for creation and maintenance of the network. For such traffic, minimum delay is desirable. Therefore BeMAP utilizes NCS for such data packets. 'Time Critical tactical messages' are specific to military scenario which requires channel availability all the time to minimize delay and reliable delivery of data. Since every node in each cycle sends its NCF in its NCS, BeMAP schedules such data packets in NCS. The periodicity of NCS should be kept as per allowable latency of such data packets.
PRAS and NCS can also be utilized for multicast and broadcast traffic. Because of the broadcasting nature of such slots, no negotiation is required to be done beforehand between source and destination. For such services slots will be acquired for multiple cycles by the source node which is not an issue in NCS and can also be handled in PRAS.

Adaptive NCS Cycle

In dynamic TDMA the control slots are required to effectively exchange the network management information. Each node in the network is required to send network control information periodically to maintain its synchronization, as well as to resolve the transmission conflicts. Some protocols uses static slot allocation for control information exchange [7] which ensures every node gets a transmission opportunity after a fixed period of time. It helps a designer to choose synchronization schemes, clock accuracy (ppm) as well as estimate for node entry and node departure time. The allocations of control slots are generally based on network ID. In such schemes each node gets one NCS and total control slots are equal to network size. The mechanism of NCS allocation to nodes is decided at the design/pre-deployment configuration time. Therefore in such schemes the TDMA frame size, latency issues are governed wrt maximum number of the nodes the network has to support. However due to mobility, node density keeps on changing in wireless network as each node has a limited transmission range. Once a node moves out of transmission range of a subnet its NCS bandwidth goes unutilized wrt that subnet. Therefore the fixed control slots techniques does not utilize bandwidth efficiently and cannot support better delay performance even if there are very less number of node in the network than the maximum network size.

In BeMAP we have developed a technique to make number of NCS adaptive to the degree of the network eliminating the adverse effects of fixed control cycle TDMA schemes. The protocol is designed to provide deterministic access for network members based on node ID to exchange their control information.

In BeMAP the NCS carries all the information those are required to realize the overall functionally of the protocol including scheduling of traffic in data slots as well as adapting NCS cycle to network degree. The NCS includes following fields.

< NCS_OI>, <SCH_IF>, < HARD_RES_IF >, <SOFT_RES_IF>, <SLOTS_AVAILABLE_FOR_CONTENTION>, <NEIGHBOR_TABLE >, <ROUTING_CONTROL_MSG>, <VC/SR_CONNECTION_MANAGEMENT_MSG>, <ACK>

***NCS_OI**: The NCS occupancy info is a small data structure required to indicate the occupancy of the NCS slots and to manage adaptive NCS cycle to accommodate new nodes. This field includes:

< SOURCE_ID >, <SELF_NCS_SLOT_NO >, <CURRENT_NCS_FRAME_LEN>, <NEIGHBORS_NCS_OCCUPANCY_BITMAP>, <MAX_NCS_LEN >, < NCS_SWITCH_BIT>, <RES >

The periodicity of *NCS_OI* in NCS is every Cycle. We will elaborate it further when we discuss network setup procedure later in the paper.

***SCH_IF**: Scheduling Info fields contain three bitmaps[3] required for conflict free scheduling of RAS. These three bitmaps includes-
<NODE'S SELF-TRANSMIT SLOTS BIT MAP>, <NODE'S SELF-RECEIVE SLOTS BIT MAP > AND <NODE'S NEIGHBORS TRANSMIT BIT MAP>.

***HARD_RES_IF**: Hard reservation info field is a slot bit map corresponding to the data slots that are scheduled for RAS.
***SOFT_RES_IF**: Soft reservation info field is a slot bit map corresponding to the data slot those are scheduled for soft reservation. If the source node that has soft reserved the slots is not transmitting data in the current cycle, slots are considered available for contention access.
***SLOTS_AVAILABLE_FOR_CONTENTION**: It is a data slot bit map indicating the slots available for contention access.
***NEIGHBOR_TABLE**: It is a table of one hop neighbor to determine the IDs of contender nodes for a contention slot. Every node on the basis of all received one hop table generates the node IDs of all two hop contender nodes to determine the access right of slots in PRAS.
ROUTING_CONTROL_MSG: This field carries control packet of network layer for routing management.
VC/SR_CONNECTION_MANAGEMENT_MSG: This field is used to exchange connection management information including connection/slot Request/Reply and connection Termination. The periodicity of connection maintenance packets depends on individual signaling protocol.
ACK: Data ACK bit map indicate in which slot a node correctly receives the data packet during last cycle.

In NCS structure great care has been taken to keep the overhead as minimum as possible. We have used bitmaps to indicate status of various slots in different context. The size of NCS can further be reduced by doing the binary coding of nonexclusive bitmaps of same size. However we are not using it in the paper to keep it simpler for explanation. Due to random traffic generation and topology change, the NCS is not required to carry all the fields all the time. The various field and their periodicity is shown in table 2. If at a given time more number of data info (larger than the size of NCS) are queued, data to be sent in current NCS is decided on the basis of priority.

Table: 2: NCS field's periodicity and Priority

Sr#	Fields	Periodicity	Priority
1.	NCS_OI	Every Cycle	0
2.	SCH_IF (Bitmap)	Every Cycle	0
3.	HARD_RES_IF(Bitmap)	Every Cycle	0
4.	SOFT_RES_IF(Bitmap)	Every Cycle	0
5.	*SLOTS_AVAILABLE_FOR_CONTENTION*(Bitmap)	Every Cycle	0
6.	*NEIGHBOR_TABLE*	Depends on average tx range and node speed.Generally 5 to 10 sec	1
7.	*ROUTING_CONTROL_MSG*	Specific to the Routing protocol implemented	2
8.	*VC/SR_CONNECTION_MANAGEMENT_MSG*	Traffic dependent	3
9.	*ACK*(Bitmap)	Every Cycle	0

Network setup/population procedure
On startup a node scans for predefined cycle duration. As a result of network scanning following case may arise.

Case1: *The node does not detect any known wireless activity*
The node assumes single node network and create NCS length of size 2(= 2^1). The NCS size is assumed to be in power of 2. The node chooses its own NCS slot at the left most available NCS fields. In this case the first NCS.

The NCS_OI data structures of the example node will be:

NCS_OI: <ID_1>, <1>, <2>, <10>, <D>, <0>, <0>

We assumed node id = ID_1 and 'D' is max Degree of the network decided at the design or pre-deployment configuration time. Therefore NCS_OI will be:

Case 2: *The node detects NCS of some other node*.
It means the node received NCS of some other node. In this case it will select the least unoccupied NCS to transmit its own NCF.
Its own NCS_OI will be:

NCS_OI: <ID_2>, <2>, <2>, <11>, <D>, <0>, <0>

Now it becomes a two node network and both nodes can exchange data as per slot reservation rules. We are not discussing the reservation procedure in this paper due to page limitation.

New node Entry Procedure with NCS cycle Expansion:
When a new node tries to join the network of two or to the network where "NCS occupancy bit map" contains all 1s.

The new node will select the NCS slot after taking the UNION of "NCS occupancy bit map of one hop neighbors" of all NCS_OI received during scan period in case of network merging.

The new node (assume ID3) will transmit its NCF in NES. With following NCS_OI.
NCS_OI: <ID_3>, <3>, <4>, <1110>, <D>, <0>, <0>

On receiving NCS_OI of ID_3, node ID_1 and ID_2 will increase their "Current NCS frame len" to 4. As shown in figure below.
NCS_OI: <ID_1>, <1>, <4>, <1110>, <D>, <0>, <0>
NCS_OI: <ID_2>, <2>, <4>, <1110>, <D>, <0>, <0>

It takes only one cycle to join a network assuming new node is synchronized and the new node is successful in sending its NCF in NES.
At this time the TDMA Cycle will look like:

NES	**NCS1**	**…**	**NCS 3**	**NCS_FREE**	**Data1**	**…**	**…**	**DataN**

Figure 2: BeMAP TDMA Cycle

When the cycle has some "NCS_FREE" slot, these slots can be availed for data exchange under PARS but not for SR.
Similarly nodes can join the network until the degree of network reaches to the predefined limit "D". In that case The Cycle will be like:

NES	**NCS1**	**…**	**NCS D-1**	**NCS D**	**Data 1**	**…**	**…**	**DATA (M-(D+1))**

Figure3: BeMAP TDMA Cycle

Collision avoidance in NES:
If two or more nodes try to join the network at the same time, they will send their "NCF" in NES and collision will take place.
In that case the contending nodes will come to know about the collision when they would receive the NCF (NCS_OI) of other nodes with unmodified "NCS slot len". To resolve the contention the contending nodes will run a random backoff algorithm.

Initially nodes will set their backoff counter to one and chose arbitrarily between 0 and 1 cycle waiting time before sending "NCF" in NES. If "NCF" successfully transmitted, the node will join the network as per procedure explained above and reset its backoff counter.

If further collision takes place, the node will increment its backoff counter (i.e. 2) and will chose arbitrarily between 0, 1, 2 and 3 cycle waiting before sending "NCF". If further collision takes place the procedure will be repeated with increased backoff counter until successful transmission of "NCF" or when backoff counter reaches to the value of "D-1", as In worse case there could be "D-1" nodes those can contend to join a single node network.

Reconfiguring NCS if some node leaves:
There could be two cases:

i. Abrupt departure:
ii. Controlled departure

Abrupt departure:
If a node leaves the network due to random mobility, sudden power down or because of any other reason those cannot be controlled. This kind of departure is detected by neighborhood nodes when they receive no NCF in corresponding NCS for some predefined numbers of continuous cycles. The neighbors reset their NCS occupancy bit corresponding to the departed node. In this case, the node which occupies the rightmost NCS, first ensure NCS fee status by computing the UNION of all neighbors *<NEIGHBORS_NCS_OCCUPANCY_BITMAP>*. The node then send its NCS_OI with <SWITCH> bit set to 1 in its present NCS.
NCS_OI: <ID_X>, <Leftmost unoccupied NCS>, <N>, <As per the network state.>, <D>, <1>, <0>
On the reception of this NCF the neighbor nodes will make change in their <NEIGHBORS_NCS_OCCUPANCY_BITMAP> as per the NCS switching suggested by node ID_X. On reception of this confirmation from neighbors, the node X will switch to new NCS. And the rightmost free NCS slot will become available for PRAS.
Controlled departure:
A procedure with some extra fields (RES) in NCS_OI can be developed to suite the implementation.
The free NCS slot will be available for PRAS.

SIMULATION

Bandwidth efficiency of the protocol was evaluated with respect to fixed TDMA protocol. The scenario is created in QualNet Network Simulator[9] in which we assumed network of total 32 nodes and as per the rules of static TDMA 32 timeslots are kept in one frame, each slot carries traffic data of corresponding node.
The physical channel data rate is selected 1Mbps[8]. The slot duration is selected 4ms. Hence the TDMA frame duration is 128ms.The slot capacity with respect to channel data rate is 4096 bits per slot. However the actual payload will be much more less,as considerable time will be used for guard time. To make comparative study of TDMA and BeMAP the frame duration of BeMAP is also chosen as 128ms, and to accommodate up to 32 nodes the value of D is kept as 32. The data traffic slots are also kept 32.

For simplicity we assume equal time duration for both NCS and traffic slots.Therefore total slots of protocol i.e. M = 64.Duration of one time slot comes out to be equal to 2ms.The traffic slot capacity with respect to channel data rate is 2048 bits per slot.

In this case we are assuming guard time as zero as our focus is the bandwidth utilization for traffic data in case of dynamic node joining and leaving due to mobility of the nodes.In this simulation we started the simulation with two nodes and logged the value of number of traffic slot available. We further activated nodes as shown in table 4, at certain time to simulate joining due to the mobility.

Table: 3: Node Activation

Node Identifier	Activation time in seconds	Total nodes in the network
Node1, Node2	0	2
Node3, Node4	5 ,5+Δt	4
Node5, Node6,	10, 10+Δt	6
Node7, Node8, Node9, Node10, Node11, Node12, Node13, Node14, Node15, Node16	15, 15+Δt, 15+2Δt, 15+3Δt, 15+4Δt, 15+5Δt, 15+6Δt, 15+7Δt, 15+8Δt, 15+9Δt, 15+10Δt	16
Node17, Node18, Node17, Node20, Node21, Node22, Node23, Node24	20, 20+Δt, 20+2Δt, 20+3Δt, 20+4Δt, 20+5Δt, 20+6Δt, 20+7Δt, 20+8Δt	24
Node25, Node26, Node27, Node28, Node29, Node30,Node31, Node32	25, 25+Δt, 25+2Δt, 25+3Δt, 25+4Δt, 25+5Δt, 25+6Δt, 25+7Δt, 25+8Δt	32

Here we kept Δt = 2 TDMA frame duration i.e. 256ms to avoid collision in NES slots.

We sun the simulation for 30 seconds and at simulation time of 4, 9, 14, 19,24 and 29 sec we logged the status of traffic slots as by this time all nodes of the activation group have sent their net joining infos and BeMAP also takes two cycles furthers to allocate NCS slot to the new node.

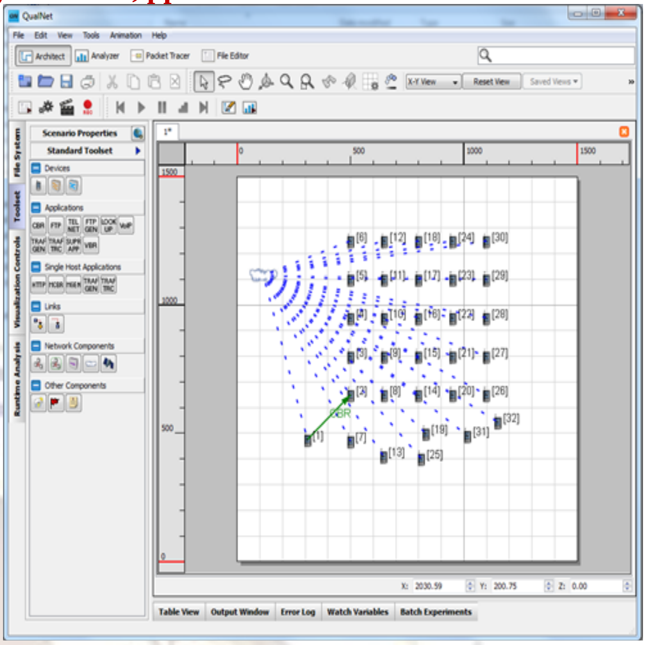

Figure 4: Simulation Scenario in QualNet

We assigned CBR traffic between node 1 and node 2 as source and destination respectively with no buffering as to avoid the effects of queuing and to keep the performance only based on protocol only. As shown in figure 5(a), at time of start of simulation the bits per frame (bpf- bit rate normalized to frame duration) of node 1 for CBR is high and gradually decreases as network degree increases due to node joining.

The capacity of Static TDMA for node 1 is constant throughout the simulation as node activation doesn’t affect here. Even at the full network degree the bpf of our protocol is more as here also all the data traffic slots are for the disposal of Node1as it is the only node generatingtraffic in present scenario.However the performance of TDMA over takes the BeMAP in case of fully connected network and when each node is engaged in communication which is a not a common case for mobile networks. For example when there are all 32 nodes are active and lest assume first 16 nodes have traffic for other 16 nodes. In this case bfp of BeMAP is 32768 in comparison to 65536bfp of TDMA as shown inFigure 5(b).

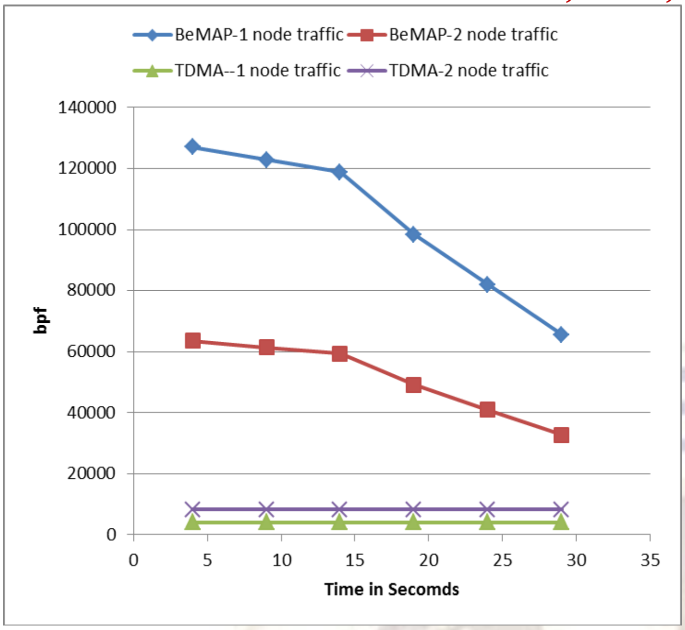

Figure 5(a): Data bandwidthfornode1and node2 inbpf

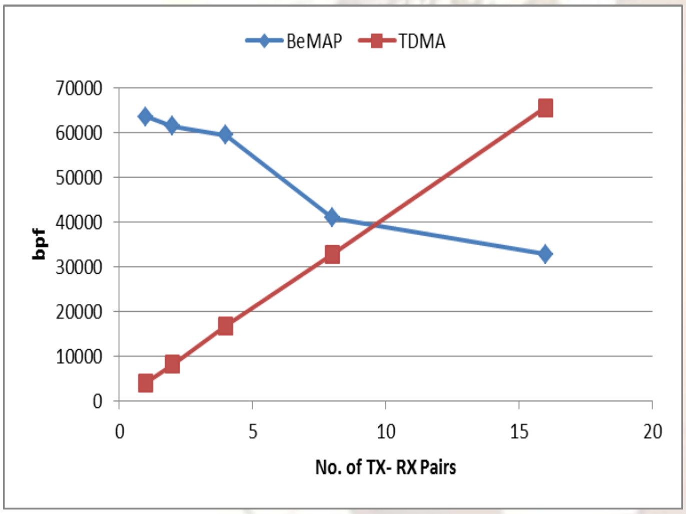

Figure 5(b): Data bandwidth for fully populated for variable TX-RX pairs

CONCLUSION

In this paper, we have proposed a bandwidth efficient dynamic TDMA slot assignment protocol to improve the channel utilization.Our protocol avoids the increase of unassigned slots by minimizing the number of control slots to the degree of present neighborhood. Moreover, being the frame length fixed the TDMA slots can be utilized for traffic purpose. The traffic generated from a tactical radio node is also categories based on its QoS requirement. By using an example of 3 nodes, we explained the adaptive NCS cycle, which not only, can extend to meet the increased network degree node but can also shirk to optimize the bandwidth utilization. Finally through simulation bpf is compared with TDMA. The BeMAP can also easily fit with any routing protocol to reserve end to end resources for VC and SR.

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