INVESTIGATING COMMUNICATION ARCHITECTURE FOR TACTICAL RADIO NETWORKS DESIGN

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ABSTRACT

Tactical applications pose unique requirements for the network, including decentralized control, vulnerability to jamming and electronic warfare, and mission critical latency bounds for end-to-end data delivery. Moreover, a tactical network is generally composed of mobile nodes and the routing protocols must deal with a range of node mobilities and time varying channel conditions. The goal of this paper is to define the best way to utilize existing technologies to improve the robustness, capacity, and quality of service of the network.

To achieve its goal, paper investigates various radio communication aspects of tactical networks under the restrictions of radio design. The main focus of the paper is, understanding network formation of tactical forces and suitably suggest communication services to meet various operational requirements. The paper also discusses overall communication architecture to enable QoS in for multihop networked services. Protocols for MAC, routing and techniques for radio resources and terminal design are also recommended concerning the realization of fully functional tactical communication networks. Simulation study of routing protocol for the main characteristic of tactical formation i.e. group mobility is also presented

Keywords: *Tactical network, MANET, MAC, Routing, Radio resources.*

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I. INTRODUCTION

Communication plays very important role in today's battlefield, which is increasingly getting digitized. It helps in mission planning and execution of wartime operations effectively by all the people involved, - both fighting troops and those managing and taking decisions. Tactical communications networks use wireless technology to achieve a high degree of mobility. Unlike cellular networks where centralized infrastructures (base stations) are static, tactical communications networks cannot rely on static infrastructure for following reasons [1].

a. *Fixed nodes are more vulnerable to enemy attacks*
b. *Highly mobile military forces need networks that are equally mobile*
c. *The need for military networks to continue "in operation" even when some nodes are destroyed and/or some links are jammed*.

Success on the battlefield depends on the ability of commander's and supporting staff/infrastructure to process rapidly the huge quantity of information presented in timely manner. This information, in addition to traditional push-to-talk voice, requires support of data traffic in a single radio. to fully meet the operational requirement of a network deployment and optimal use of radio resources, the traffic services are required to be customized. Other challenge in tactical networks is minimizing over the air collision and maintaining reliable operation in situations when all radios are not within range of each other. To ensure a robust network, distributed network control architecture is required to be adopted.

In this paper, first we explore Network Organization & Topology. In next section Communication Services and their characteristic based on network topology and operational requirements are presented. For realization of such networks, requirements and protocols are suggested for Media Access Control, Addressing and Routing, Radio Terminal & Resources in separate sections. The performance of routing protocols for network scalability and group mobile communication for CBR traffic is also evaluated, before drawing the conclusion.

II. NETWORK ORGANIZATION & TOPOLOGY

The current war-fighting philosophy places a premium on information superiority on the battlefield and it is predicated on the ability to achieve an Internet-like capability in operational areas, providing ubiquitous network access to enable "anytime, anywhere" communications. This capability is to be provided by a varied collection of networks, including a high-capacity optical fiber backbone, satellite networks, terrestrial broadband wireless networks, shipboard, airborne, and ground-based wired and wireless local area networks, and soldier-based personal area networks.

Front tactical network are deployed in a region of highly dynamic in nature, consisting of a variety of network elements, largely comprised of mobile, wireless nodes on a variety of platforms, including vehicular, dismounted soldier, and temporary fixed (but nomadic) sites. As the tactical operations, so often take place in locations where usable infrastructure is scarce, nonexistent, or unsuitable, MANET (Mobile Ad Hoc Network) technology is attractive, as it would enable the formation of networks on demand as the need arises.

A typical topological organization for tactical formation is shown in Figure-1.

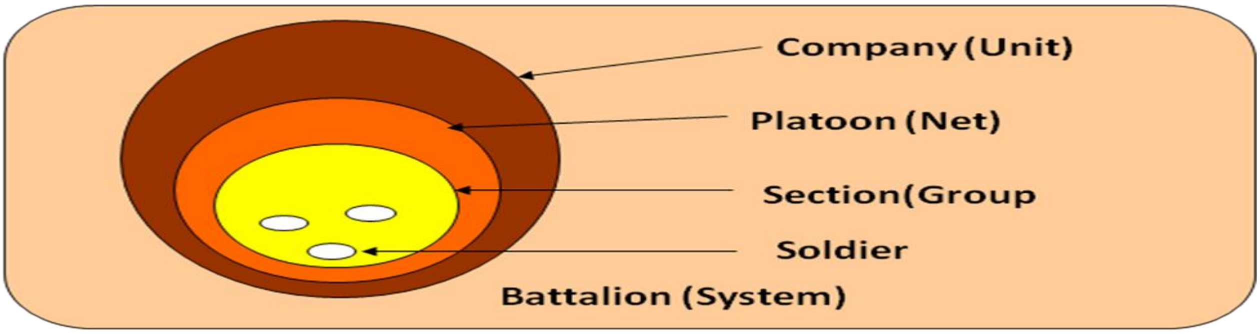

Figure -1: Organization topology for tactical formation

Usually a section is formed consisting of dismounted soldiers assigned a common task. It is also possible that a soldiers' membership may overlap between other sections based on certain situational assignment but unusually membership in one section is dominant at any given time. A section is associated in platoon. The platoon generally has more than one section. Similarly platoons creates company, which is further a part of a battalion; a higher-system level warfighting unit. This arrangement provides a natural hierarchy that can be used to scale the network in terms of numbers of nodes as well as coverage area. The section/platoon network deals with connecting a soldier to other soldier or to vehicle based their leader. Whereas platoon/company network generally relies on vehicle to vehicle (v2v) or vehicle to fixed (v2f) command post; which could be transportable.

III. COMMUNICATION SERVICES & CHARACTERSTICS

A. Communication Services

To meet the operational requirements of tactical forces a variety of services must be supported by the communication network. Each service should cater for the specific need of user and must be optimized for that specific operational need. Broadly communication services can be divided into voice and data but these two general categorization of services does not reveal the actual communication that takes place in tactical scenario. Hence, an array of communication services are proposed, those reflect the operational communication need of tactical forces. These services also fit well with tactical formation. The services are summarized in Table-1.

Table-1: Communication services for tactical soldier network

Voice Service	Details
Selected (P2P) call	Point to Point call within the Group of the individual caller
Group(Broadcast) call	Broadcast call within the Group of the individual caller, it will be heard by all members of that particular group
Inter Group (P2P) call	Point to Point call across two Groups of same Net
Inter Group (Broadcast) call	Broadcast call across two Group of same Net
Net(P2P) call	Point to Point call across two Nets
Net (Broadcast) call	Broadcast call across two Nets
Universal call	Broadcast call without any addressing restrictions, will be heard all, within transmission range
Emergency Call	A call invoked by pressing an emergency key, the ID of the radio is transmitted immediately.
Request to Talk	A key, when pressed forwards(in transmit queue) a template to the destination as per the present radio configuration
Data Services	
Status Messaging	A field user forwards one of the set of predetermined messages concerning to user status.
C2 Messaging	Command & control messages containing critical operational information
SMS	A short text message that is prepared and set between users (advice or alarm etc.)
File Transfer/Email	A long data file containing detail reports to command post
Tactical chat	Interactive short message exchange between peers
Information Query and Retrieval	A master application used by the commander for configuration and management
SA	Situation Awareness messages containing information required for a field personnel to perform specific task, geographical info, vehicle location etc.
Image	A application for transporting medium and high resolution images
Video	Slow scan to full motion video

The important features for voice/data communication should also include the following.

a. *Provision of priority level with preemption*
b. *Security including encryption and authentication*
c. *Caller identification*
d. *Provision for Interoperability with other networks*
e. *Voice performance in high noise hostile environment*
f. *Provision for remote RSSI check*

All voice oriented services are the primary application in low data rate dismounted user waveforms. While data services can be multiplexed with voice for better utilization of the spectrum. Image and video services are not frequently used applications which are inhibited by scarcity of spectrum, but more suitable for communication between two central command points. All these service call types are half duplex as the call initiator activates a push to talk (PTT) key for the duration of the transmission.

B. Quality of Service

The different types of services place specific demands on packet delays and packet losses in order to be fully achieve their objective. For example, as the human ear is very sensitive to delays, voice transmission demands low delays. File transfer and e-mail, on the other hand, have a much higher delay tolerance. Traffic can also have QoS demands for non-technical reasons also, such as the importance of the information it carries, e.g. C2 should take precedence over all other messages in a tactical network. Typical QoS parameters for selected services are listed in Table-2.

Table 2: QoS requirements for different tactical services

Service Type	BER	Priority	Delay
Low bit rate voice (Real Time)	10^{-2}	High	Highly sensitive (< 250 ms)
Emergency Call (Critical)	10^{-4}	High	Highly sensitive (250ms -5 sec)
SMS (Best Effort)	10^{-3}	Low	Very Tolerant > 10 sec)
Tactical chat (Non Real Time)	10^{-3}	Medium	Tolerant (5ms -10 sec)
C2 Message (Critical)	10^{-3}	High	Highly Sensitive (250ms -5 sec
File Transfer (best Effort)	10 -6	Medium	Very Tolerant (>1 minute)
Video (Real Time)	10 -6	Medium	Highly sensitive (< 250 ms)

In addition to the priority and delay the packet loss ratio is also an important metric. However from user's perspective packet loss manifests itself as delay for non real time application where transport protocol assures delivery by using repeated request and acknowledge procedure.

C. Traffic Characteristic

Experience with using the Internet shows that the amount of data that occurs in such a military network can be significant. Communications systems based on wireline channels can easily handle a large amount of data traffic. However, they cannot meet the requirements for high mobility and independence from infrastructure. Therefore here the challenge is provide user ruggedized internet like services in a mobile environment.

Specific to soldier network group calls where the voice traffic is usually the dominant traffic type, therefore MELPe [2] (600/1200/2400 baud) and CVSD (16/64Kbps) [3] can be used as voice coding/compression algorithms. Table -3 lists few selected communications traffic and required transmission rates [4]. Clearly, video displays and image-intensive access to databases will place the greatest demands on transmission rates and power. For other services like SA which require a periodic update that network features can be exploited. It can be combined with periodic MANET control message update.

Table – 3: Communication traffic & required throughput

Ttaffic	Required Throughput (kbps)
Speech	8–32
Short messages	1.2–9.6
Electronic mail	1.2–64
Video	64–384

IV. NETWORK ARCHITECTURE

For the design philosophy of a network, the OSI is the guiding standard. The top four layers residing in host device, commonly called as higher layers. The network layer provides a common interface to interconnect various networks. Data link and physical layers are machine specific and deals with node to node delivery of message. This OSI model is theoretical framework for the design of a network. This enables modular, layer-wise system development and standardization of component. On the other hand in practical system, this modularity cost in terms of overhead. Even in resource rich wired network where TCP/IP is de-facto standard, presentation and session layers are not_present.

In general the network functionality can be divided in four major layers; Application, Internetwork, Core Network and Physical (Figure-2). The core network is the component that defines the basic networking. Therefore to achieve the basic MANET functionality, we require up to core network components. The higher layers can added be depending upon the sophistication of the service those will run on MANET. Since higher layers also increases overhead and latency; a cross layer approach to can be applied in design to diminish adverse effect of layering in resource constraint tactical mobile network.

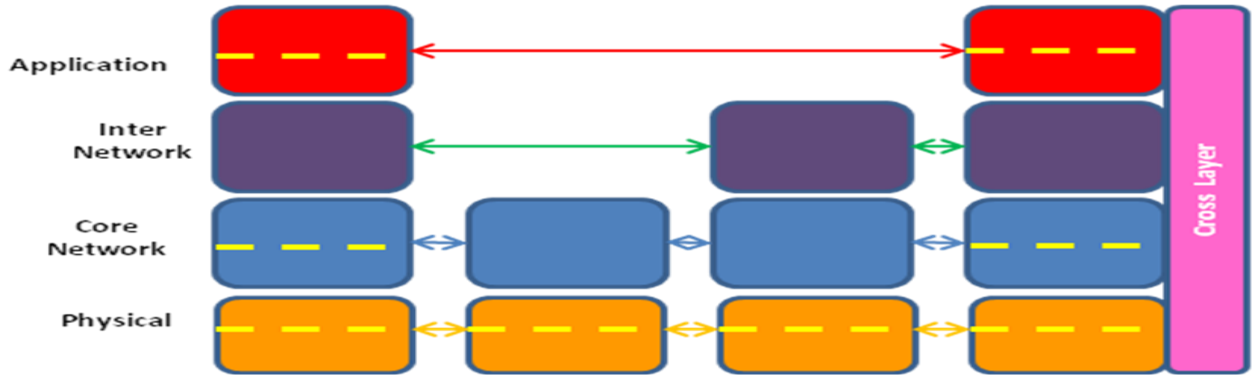

Figure-2: Network Stack

The job of core network for MANET can be further divided into two main functions. First is to avoid collision by scheduling transmission, which is done by MAC and second is to find the suitable path for Multi-hop transmission to reach the destination that is routing.

A. Media Access Control

An import aspect of tactical MANET is medium access control (MAC). The MAC protocol is needed to provide efficient and fair sharing of the radio channel resources. The protocol should cover a wide range of network connectivity, from a shared broadcast channel to the multihop store-and-forward MANET topologies. The tactical adhoc network requires QoS guarantees for the voice service, and for other time sensitive services as well. Contention protocols do not normally provide this option, nor stability under heavy load conditions. Therefore reservation based or hybrid protocols can be a candidate for tactical network. However the selected MAC protocol for the network must be evaluated for energy efficiency, fairness and its implementation should be simple & decentralized. A proper design not only guarantees successful information exchanges among nodes in the presence of conflict but also maximizes throughput [5].

The wireless hosts have battery supply. The nodes need to be energy conserving so that total time in which the network is connected and functioning is maximized. To design an energy-efficient MAC protocol, it is required to consider the factors those causes energy waste from the MAC perspective. These include:

Collision is a first source of energy waste. Follow-on retransmissions consume energy too. Collision is a major problem in contention protocols, but is generally not a problem in scheduled protocols. A second source is ***idle listening***. It happens when the radio is listening to the channel to receive possible data. Many MAC protocols (such as CSMA) always listen to the channel when active. A third source is ***overhearing***, which occurs when a node receives packets that are destined to other nodes. Overhearing unnecessary traffic can be a dominant factor of energy waste, when traffic load is heavy and node density is high. The last major source that is ***control packet overhead***. Sending, receiving, and listening for control packets consume energy. Since control packets do not directly convey data, they also reduce the effective throughput.

Another key factor in the design of a MAC protocol is the way in which it utilizes the available medium. Earlier approaches assumed a common channel for all stations, while more recent approaches have used multiple channels for more efficient use of the medium. These protocols separate the control and data planes by assigning one channel for control signaling and one or more separate channels for data transmissions. BTMA [6] suggests having a separate busy tone channel to solve the hidden terminal problem of CSMA [7]. Time Division Multiple Access segments the medium by splitting it into several fixed time frames that are subdivided into slots. To ensure that nodes keep track of time frames and slots, TDMA protocols require time synchronization among the nodes. TDMA Slot reservation is one method to guarantee QoS and therefore an interesting concept when transporting real-time traffic such as voice. TDMA based techniques are potentially better suited to networks with heavy or unbalance work load. The Dynamic TDMA algorithm, that divides the channel into slots exploit spatial reuse of the radio channel based on priority and bring better channel efficiency.

There are number of dynamic TDMA protocols published [8], [9] tactical MAC application. However the implementation clarity in existing MAC protocols is required to incorporate new node joining procedures/ collision resolution and cross layer interaction with routing layer for end to end path bandwidth reservation so support QoS in mobile environment.

B. Addressing and Routing

The addressing is needed to support basic network formation, mobility management, security provision, routing as well as network management. All radios should have unique network addresses, enabling loop-free unicast, and multicast routes. It is foreseen that user roles in the military organization may have an impact on the addressing scheme, however, role based addressing may be handled by higher layers as well. Hardware based network addresses (one example is the IEEE MAC) is one possibility. Moreover it is desirable that each user's unique address consists of part of user radio hardware address. It should also have a part of global significance number. The global significance number should to be identifiable form outside the platoon/company. However the need for auto addressing is also felt [10]. In which address allocation can be performed with minimal or no user interaction. In tactical scenario the most popular form of arranging nodes is hierarchical structure. This structure is based in geographical location and chain of command into small clusters. Network clustering of mobile nodes offer some key advantages, such as extension of network coverage by spatial reuse and ability to scale to large and dense networks. To support the of group/ net call type communication services, the routing protocol must be capable of scaling to large dense networks consisting of hundreds of radio nodes and supporting group mobility.

To evaluate the performance of routing protocols for network scalability and group mobile communication, we conducted an experiment for performance comparison of selected routing protocols for CBR traffic. The CBR is chosen as it appropriately represents the constant rate vocoder voice service. For the simulation experiment we have selected representative protocols from various routing categories of proactive (OLSR)[11], reactive (AODV)[12] and hierarchical (LANMAR)[13]. The purpose of this experiment is to observe how the routing protocols perform with ***different network size*** and ***group mobile Nodes***. In our test scenario nodes are organized into 5 different groups each group has equal no. of nodes. Group 0 is static, Group1 is a fast moving group with speed between 40 m/s to 60 m/s, Group 2 having speed between 20m/s to 40m/s, Group3 having speed between 10 m/s to 20 m/s and Group 4 is a slow-moving group with speed between 1 m/s to 10 m/s. We have chosen these parameters to simulate scalability of network and to include speed model of all the ground deployment. The common simulation parameters are as shown in table-4.

Table – 4: Common Simulation parameters

Parameters	Value
Size of region	(1500m x 1500m)
Terrain	Smooth, flat surface
Mobility	Group Mobility
Time period of simulation	5 mins.
Path loss Model	Two-Ray
Shadowing Model	Constant
Radio Type	802.11b Radio
Packet Reception Model	PHY 802.11b Reception Model
Antenna Model	Omni directional
MAC Protocol	802.11
Data packet application	Constant Bit Rate

Packet size	512 Bytes

We created seven scenarios as shown in table- 5 and all selected protocols are tested for each scenario. Traffic is generated between nodes of group 0-4 starting at 1s, group 0-1starting at 2s and group 3-4 starting at 3s till the end of simulation in all the simulated scenarios. Each CBR packet is of size 512 Bytes, and there is three source/destination pair between groups. We also simulated a case of high traffic load with 200 nodes in which we created 70 source/destination pair between groups. The average throughput and their result values are mentioned in table-5/figure -3 along with comparative result for all considered scenario.

Table – 5: Simulation result

Scenario #	**Number of Nodes**	**OLSR**	**AODV**	**LANMAR**
1	**40**	1369.67	2519.67	2004
2	**60**	1296.63	2619	1810.67
3	**100**	1396.67	2739	1373.33
4	**160**	1419	3556.67	282
5	**180**	1321.33	3447	185.5
6	**200**	1460.33	3282.33	27
7	**200 after increased traffic**	3595.5	134.27	242.61

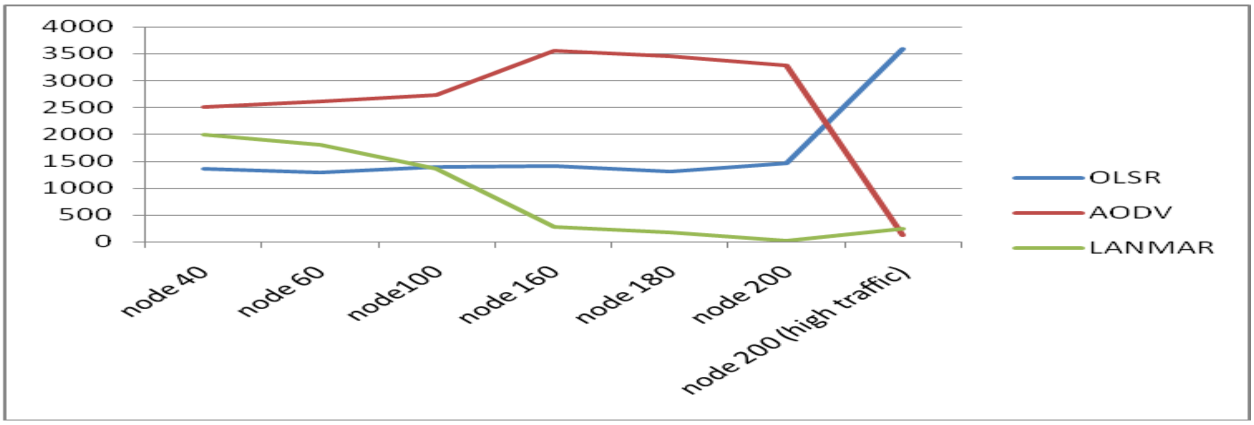

Figure-3: Comparative result for throughput

In the experiment we observe that AODV appears to scale best in response to increasing network size compared to remaining protocols. The AODV protocol performs better in the networks with static traffic and with the number of source and destination pairs is relatively small. OLSR shows a uniform, but fairly sharp increase with for high traffic. The OLSR protocol is more efficient in networks with high density and highly sporadic traffic between a large numbers of hosts. LANMAR performance is higher than OLSR till 100 nodes but starts decreasing after increase in density above 100 nodes.

C. Radio Terminal & Resources

Now coming to hardware part, the basic radio terminal should be a portable unit enabling easy carriage by the individual. Each radio should necessarily comprise a data processing unit with memory, a RF part with antenna, and provisions for power source. For soldier network, a single unit hand-held version is required as well as versions that will operate hands free. The hands free unit should probably be a wearable design with a lightweight antenna and RF elements in the head gear that includes an ear piece and a microphone; and these connect to a battery pack with a display and control panel.

The hand-held version would need to be rugged, compact, and include belt clips, headset jack, and other common accessories. The user interface must be simple, and for voice, needs only

a. An on/off and volume control,
b. Talk group/channel selector
c. A push to talk button,
d. Security authentication I- button
e. An Erase Key (for erasure of critical algorithms in case of compromise) and
f. A display

The data input device may be based on PDA data interfaces. The radio terminals should include GPS receivers to support user navigation and network resource management, and to support network functions including location assisted routing schemes and, as applicable, synchronization. The use of multi mode, multi band and multi transceiver radios, made possible by software defined radio technology, will greatly facilitate the development of flexible and low-cost (multi use) radios terminals.

The software enables dynamic control to a variety of modulation techniques, wideband or narrowband operations, and communications security functions (such as hoping) and waveform requirements of current and evolving standards over a broad frequency range. As portable radios have limited battery, hence nonlinear PA is normally used in such radios. This requires use of modulation, which can sustain PA non-linearity and can be demodulated non-coherently due to frequency hopping requirement of tactical environment. CPM satisfies these requirements. Due to trellis structure, they can be suitably integrated with convolution FEC codes to get advantage of joint demodulation and decoding (iterative processing) which provides substantial gains under multi-path conditions. For increased bandwidth efficiency of

CPM, higher order alphabet size and shaping duration may be used. SC-CPM (Serial Concatenated Continuous Phase Modulation) is one approach that addresses many of the desired goals of physical layer: robust performance, power efficiency, bandwidth efficiency and turbo-like performance. For higher data rates suitable channel equalizer scheme would be required to compensate multi-path and ISI distortion.

V. CONCLUSION

In the paper communication services required by defence forces under various operational needs are presented. To realize these services various system level requirement are also discussed. We also the presented basic user interface required for a networked handhald radio and options for MAC, Routing and physical layer. Represented routing protocols form different routing categories are also compared for throughput performance for scalability and group mobility.

Although a lot has been accomplished toward realizing multi-hop ad hoc networks, much remains to be done to achieve the design objective of tactical network. Specifically, major issues include:

a. *Layer 2 & Layer3 Routing protocols*
b. *Frequency assignments and standards*
c. *Security & authentication*
d. *Interoperation & co-existence*
e. *Network synchronization and*
f. *Network management*

As presented, the MAC and routing protocol is the most difficult outstanding technical problem. Decisions at the routing protocol layer will likely require compromises at the MAC and radio layers; particularly to support quality of service and multicast. The next-generation tactical ad hoc mobile wireless network technology [14], with innovative routing and MAC protocols is potential application for any small network (up to about 30 nodes). For large-scale ad hoc mobile wireless networks, logical clustering would almost be necessary. It will, therefore require significant advances in physical, MAC, and networking layer.

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