ECE544 Network Architecture Paper

‘Tactical Military Network’

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1. Concept for the network

Why is it needed: In the movie (Black Hawk Down, 2001[1]) U.S. Army fought with Somalian forces in heavy-crowded city. In Iraq-war (2003), U.S. Army went straight to Bhagdad without any resistance by enemy, but when it got closer to Bhagdad, things were not easy. From above two examples, modern war mainly consists of street fighting where we must take innocent citizen into consideration. In street fighting, it’s not a strong firepower but accurate tactics and strategies that we really need. Of course the essential requirement for achieving them is communication.

What are the services: The followings are the very things the tactical military network really must serve:

- #1: Wireless communication between our forces
- #2: GPS Service (for example, map downloading and positioning)
- #3: Remote control of electronic arms and weapons
- #4: Scheduler (Command/Response in time order)
- #5: Health care (temporary treatment, check and report)

Let’s look at them in more detail. Table 1 shows the detail requirement for each service.

	Message type	Supporting network type
Service #1	Voice, Data(streaming video)	Ad-hoc network (also equipped with infrastructure mode)
Service #2	Data (map, position)	Satellite network (GPS)
Service #3	Data (command/response)	Sensor network
Service #4	Additional service in handset using Service #1	
Service #5	Additional service in handset using Service #1	

Table 1: Service specifications

In conclusion, the tactical military network which we’re trying to design organizes a heterogeneous network (also called hybrid network) consisting of ad-hoc network, satellite network and sensor network.

[1] The movie based on the true war story in Somalia

Who does it serve: Service provider should be non-commercial institutions. This kind of network is designed for implementation at regional and national levels, providing voice, data and video services to support [3]:

- Strategic armed forces headquarters communications
- Internal security forces and police communications
- Air defense / air traffic control systems
- Border control / surveillance systems

Why a new design approach is needed: The properties this network should have are different from those of commercial network, i.e. cellular network and LAN. [3]

- Heterogeneous / Hybrid network
- Security & Privacy
- Reliability / Robustness
- Highly Mobility
- Surveillance / Survivability

Adding to these, end-user entity (for example, handsets given to each soldier) should have more requirements unlike network entity (gateway, router and access point).

- Compact design
- Less power consumption (Energy efficient)

Thus, we can use already existing networks for building this kind of network except that we have to design a terminal.

Usage scenarios:

The first scenario goes like this. Most communication devices are installed in mobile vehicles, tanks, trucks, etc. Also, soldiers can carry telecomm devices that could talk to a wireless base station or directly to other telecomm devices if they are within radio range. However, these forms of communication are considered primitive. At times when the wireless base station is destroyed by an enemy, a soldier will be prohibited from communicating with other soldiers if the called party is not within radio range. This is the scenario where ad hoc wireless communications come into play. Another scenario is the management of minute wireless sensors in a battlefield. Very often, prior to launching an attack, critical surveillance information of the enemy is needed. Sensors are becoming wirelessly enabled, allowing them to be scattered in targeted zones. Such sensors are able to quickly gather information about the location and environment and periodically relay this information back to the command, control, and communication center. This information is then used to influence attack strategy and determine attack decisions.[4] Last scenario says that using satellite network in combat field gives out a lot of advantages. In real time, we can locate our forces scattered in battlefield. Furthermore, we can find the shortest, safest path to the enemy through downloading map with the aid of GPS. Conclusively, you can realize that U.S. Army should've won Somalia-war if and only if they were equipped with this kind of network.

Cost factors: Not important. In military application, we can ignore the cost factors only if we can achieve the optimal performance. Due to limited customers, it is unlikely that we can save the cost factor.

2. High-level concept diagram of proposed network

Based on bottom line we mentioned just before, we can sketch what the whole network looks like. (See the Figure 1.)

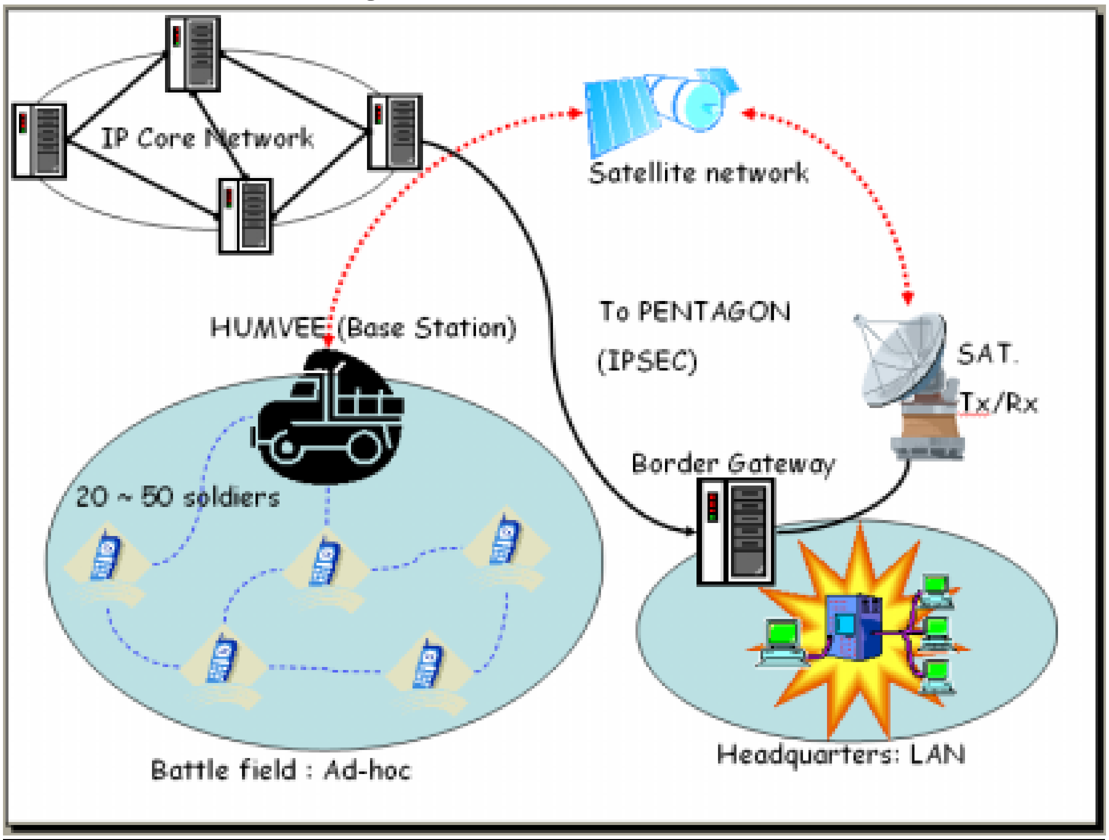


Figure 1: A typical schematic diagram for tactical military network

The figure 1 shows the conceptual diagram of tactical military network in regional scale, while figure 2 depicts the large scale network. Let's imagine the large scale network in use. The pentagon locates in Washington and headquarters are in Somalia and Iraq. The current status of battle-field in Somalia could be transferred to Pentagon in real time and the following command and strategy could also be returned to regional headquarter.

The basic service requirements running on this network are listed below.

- Transport services: Command/response is delivered over TCP/IP while streaming video data is delivered over UDP.

- Bit-rates to be supported: voice (9.6kbps), data and video (CBR, 320*240 pixels resolution with 24 bits of color information and 30 frames per second. --> 2Mbps on average if we use an efficient CODEC) [2]
- Network API: TCP/IP, 802.11 MAC, LAR (Ad-hoc routing based on position. We can implement this with the aid of GPS.) [4]
- Number of users: 20 ~ 50 users. Each base station covers up to 20 users. Thus we need 1~3 base stations. In the case of 3 base stations in use, we can organize Aloha Satellite network or TDMA-based satellite network.
- Terminal type: mobile, portable and standalone

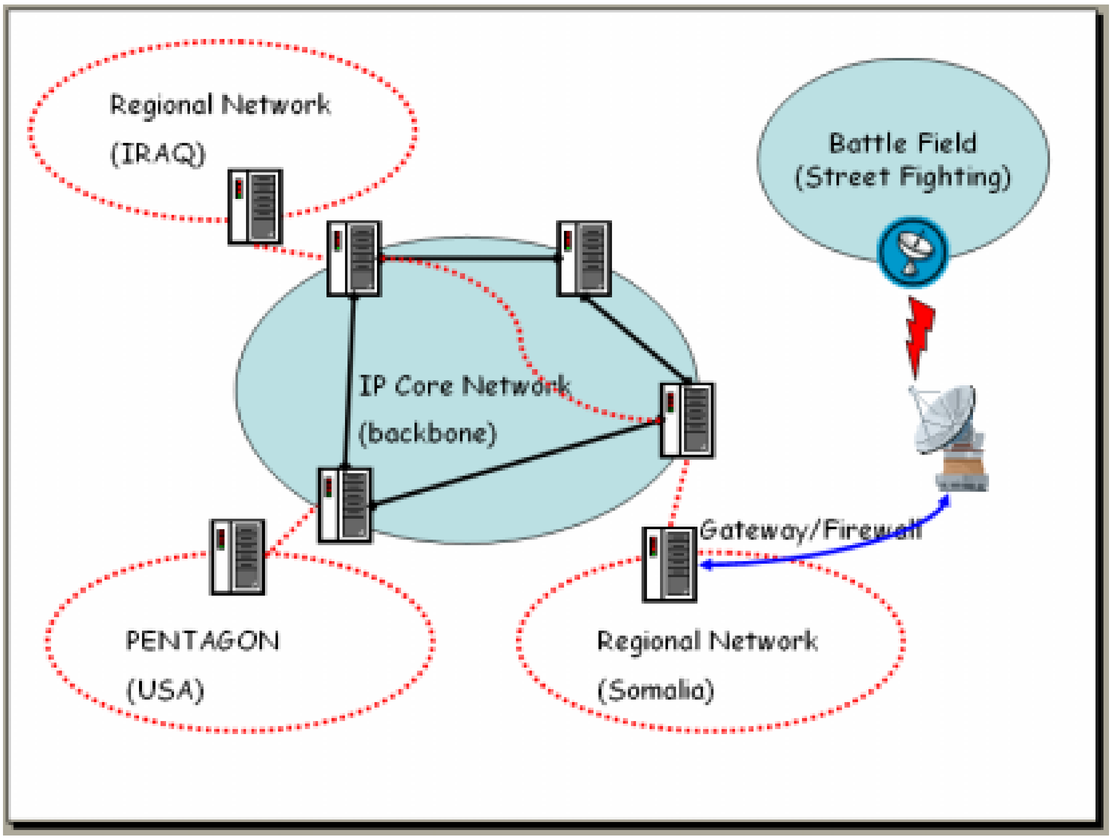


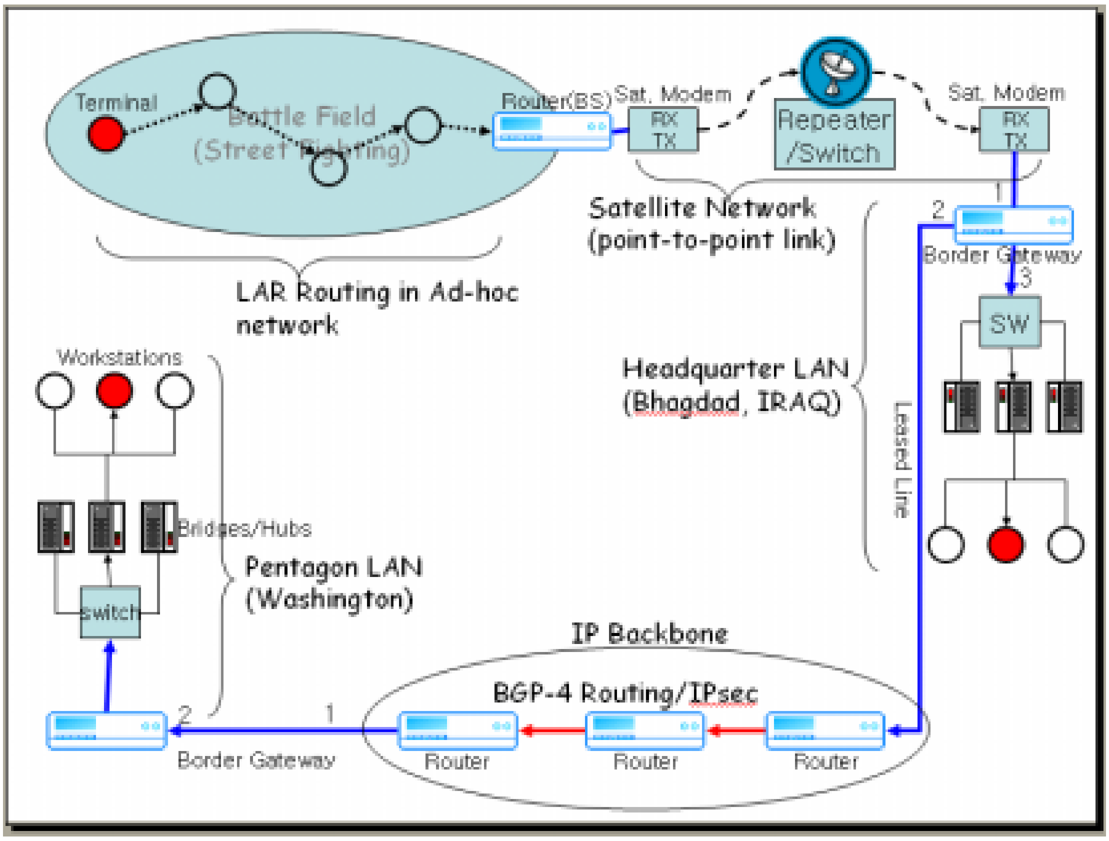
Figure 2: The extended tactical military network in large scale.

- Network topology
  - local network type: 802.3(LAN), 802.11(WLAN, Ad-hoc/Infra-structured)
  - access network type: Satellite network (Aloha or TDMA), Leased line between local gateway and core network
  - core network type: IP-backbone network (over ATM/SONET)
- QOS features: Application characteristics (Voice: real-time, intolerant and non-adaptive. Map data: real-time, tolerant and adaptive. Video streaming: real-time, tolerant and adaptive)

- <u>Availability:</u> 99.9%
- <u>Reliability:</u> 99.9%
- <u>Security features:</u> Combination of VPN, IPsec and firewalls (for wired link), WEP and Authentication with SSK (for wireless ad-hoc link) [2]
- <u>Cost:</u> Don't care

3. Network architecture diagram

We can configure the diagram of major network elements based on up-to-now discussion. <u>(See Figure 3.)</u> As you might realize, the whole network consists of five different networks: Ad-hoc network, Satellite network, IP-core network, LAN and sensor network[2]. However, I didn't take sensor network into consideration. Adding to the above diagram, the following picture <u>(Figure 4.)</u> depicts each protocol stack in network entity.



<u>Figure 3: Hardware diagram (major network elements)</u>

In implementing each network entity according to previous two pictures (Figure 3~4) which tells about protocol stack and network interface, we have to consider software and hardware specification for each entity. <u>(See Figure 5.)</u> To start with software, the

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2 Sensors are currently used for a wide array of tasks including nuclear, biological and chemical agent detection, early warning and situational awareness, target acquisition and physical security.

most important things we must keep in mind are security and embedded software (for terminal). For wireless connectivity, we take use of WEP and authentication with SSK(Shared Secret Key). Meanwhile, we use VPN with two firewalls and IPsec between LAN in Pentagon and LAN in Headquarter, IRAQ.

For terminal (embedded system), we take Mobile JVM as software platform and embedded LINUX as RTOS running on ARM-based processor. It is noted that device driver on the top of RTOS must keep, what we call, 'intelligent power consumption controller'. We have to design that terminal lasts at least 24 hours.

The remaining network entities are gateway, switches and bridges in local network. We can use CISCO commercial products for them without hesitation. (Table 2)

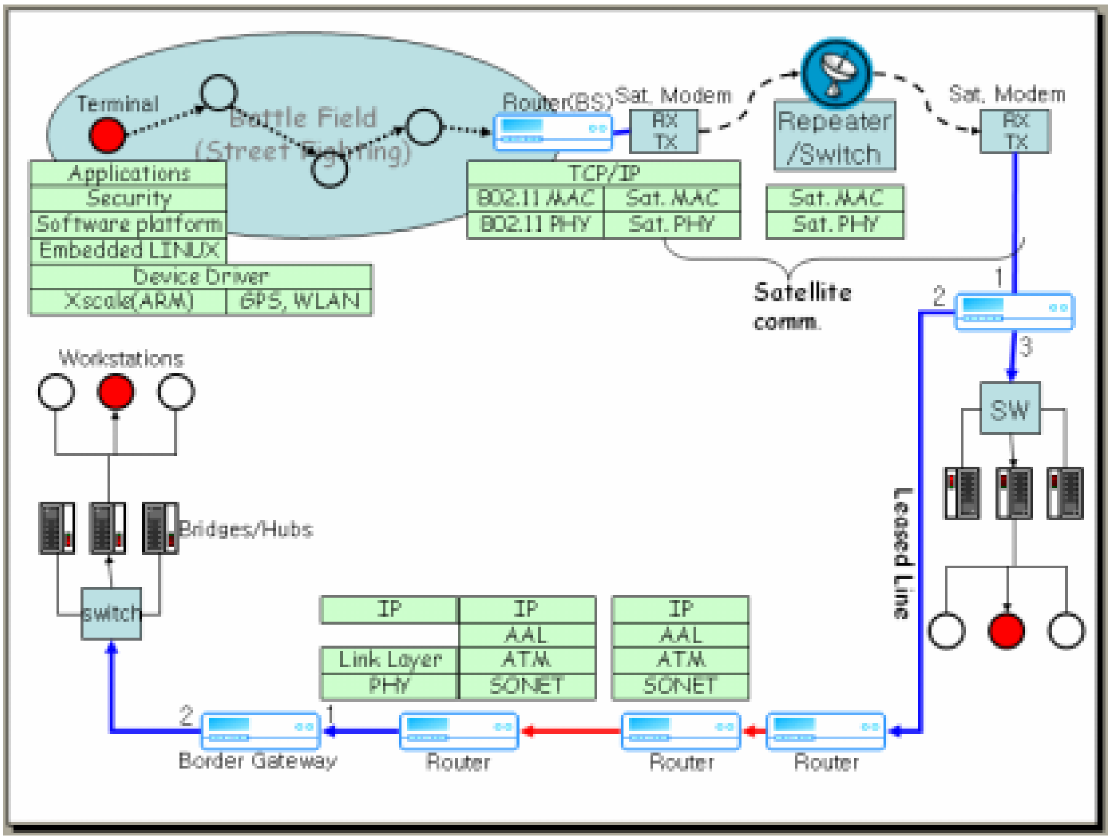
Entity	Requirements	Product
Terminal	Low power consumption, Cross-layer optimization	New Design
AP in HUMVEE	Security	Agere Orinoco AP-2000
Satellite Modem	Reliability	Hughes R-BGAN Modem
Router	VPN, IPSEC	CISCO 7200 Series
Switch	Nothing special	3Com Super Stack 4400
Bridges/Hubs	Nothing special	Allied Telesyn AT-FH700
Ethernet Firewall	Security	D-LINK DFL300

Table 2: Already Existing Products

If we redesign all network entities for optimal performance without using already existing ones, there are essential considerations for each communication layer.

[Physical/Link layer concerns]->In the street-fighting, the propagation path loss is the major factor influencing the reliable communication. Adding to this, multi-path fading invokes frequency-selective fading and mobility of soldiers gives out a Doppler effect, which results in time-varying channel. Thus the physical layer design must take care of these obstacles. A/J consideration should be taken care of also here. Lastly speaking, terminal should contain GPS transceiver and WLAN transceiver. If we use DS/SS modulation in WLAN, we can have chance to combine and optimize GPS and WLAN transceiver together because both of them use DS/SS. We can also address the design of physical layer as software radio with leaving the fast-running part in ASIC. RF parts could also be combined between GPS and WLAN (Already in commercial product.)

In link layer, some remedy for increasing TCP/IP performance over wireless link should be added. For example, retransmission scheme (RLP) and priority-based scheduling which schedule packet forwarding to multiple wireless nodes based on channel quality. This increases link utilization and fairness. [5]



<u>Figure 4: Protocol Stack diagram</u>

<u>[Network layer concerns]-></u>In wired link and satellite link, we can use conventional routing protocol as usual, but we're very careful in selecting ad-hoc routing protocol for low power consumption. LAR (Location-Aided Routing) could be one of choices which use position information in flooding and forwarding. Fortunately, each terminal knows position knowledge of whole ad-hoc network. The scenario goes like this. Every terminal receives signals from 4 GPS satellites and it transfers its own received information to base station without any processing. After base station collects all GPS information from every node periodically, it conveys them to GPS-server which calculates the whole positions of network and topology. After then, base station broadcasts (or floods) position information to all nodes in its range. Note that calculation of position with GPS received signal periodically takes a lot of power consumption, thus every node request this kind of work to GPS-server which is directly connected to base station.

<u>[Transport layer concerns]-></u>As link layer address the problem of TCP/IP performance degradation over wireless link, transport layer also take care of that together with link layer (For example, TCP-snooping, indirect-TCP and so on). [6] The most important thing is optimization of link layer and transport layer, no matter

what we choose. If each plays a role for increasing TCP/IP performance separately, it could be very painful in processing delay. (cross-layer optimization needed)

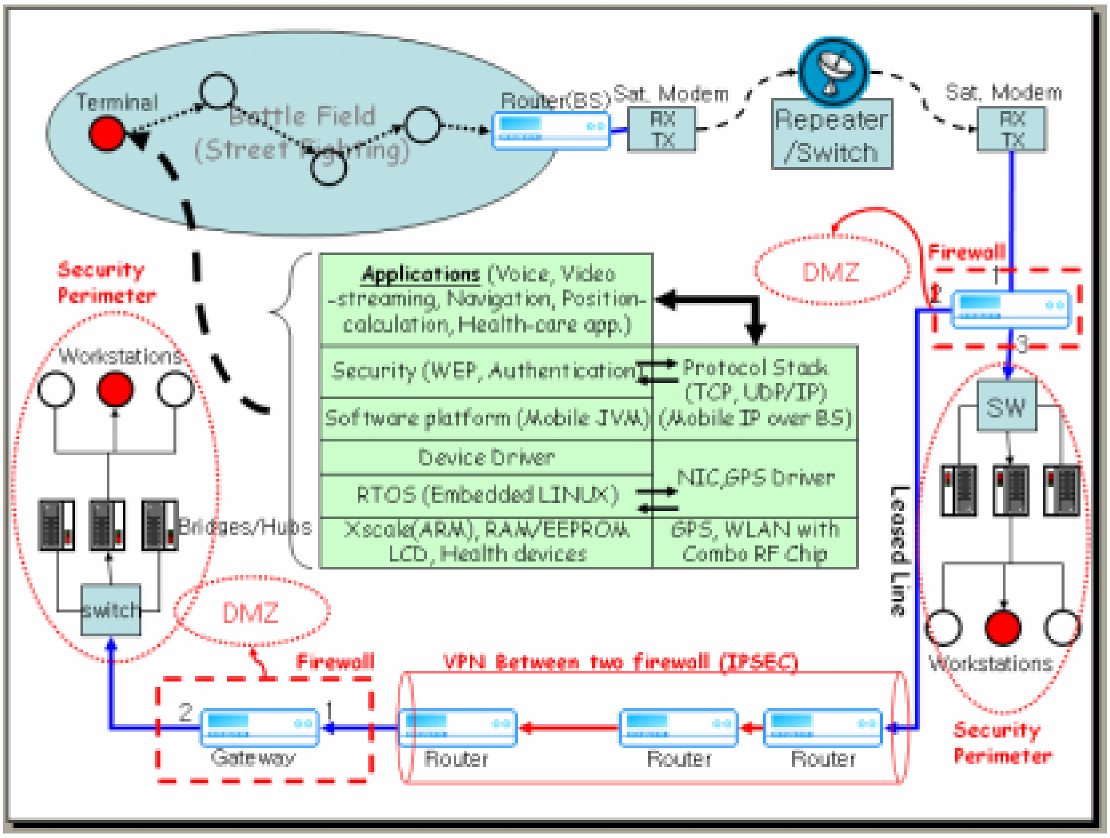


Figure 5: Software/Hardware realization in detail

4. A brief performance evaluation

For the performance evaluation of this network, I used NS-2 simulator (For Tcl script code, See the appendix) and model the whole network like this:

Simulation environments:
Wireless link between m0 and b0: 2Mbps (bandwidth) / 1ms (delay)
Links b0-d0 and d0-n2: b0, d0 and n2 are in same machine (HUMVEE). Thus very high bandwidth and no delay are assumed for modeling.
Satellite link: uplink/downlink 10Mbps, 500ms (delay)
Core network: 20Mbps, 2ms (delay)
Network API: TCP/IP (for map and position infomation downloading), UDP/IP (for video streaming)
Application: Heavy-CBR (video streaming, 2Mbps), Light-CBR (map and position,

200kbps)[3]
Error model: See the details in tcl script file.

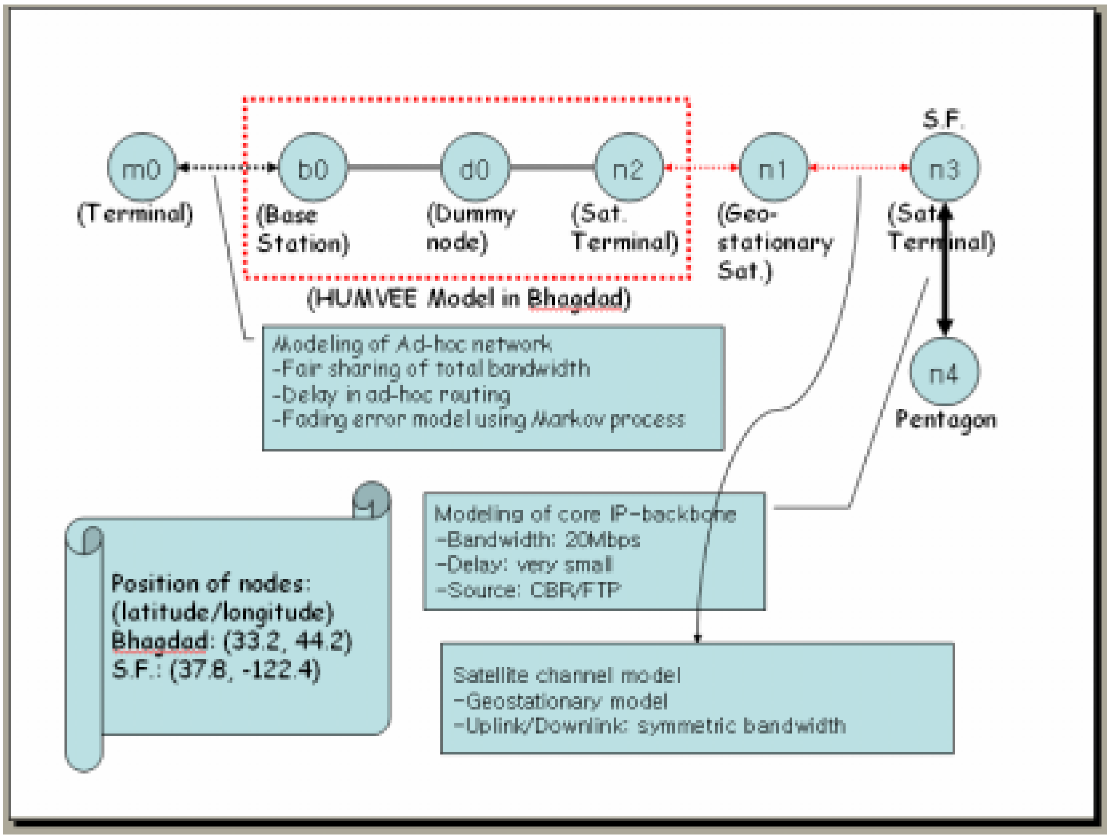


Figure 6: Target system model in NS-2 simulation

(1) Packet loss performance

	Avg. offered load (packets)	Avg. packet lost	Packet loss rate
Heavy CBR	1419045	19774	1.40%
Light CBR	265165	5434	2%

Table 3: Offered load and packet lost

(2) Delay performance: Not completed

5. Conclusion and further work

Until now, we investigated the tactical military network which is optimally designed for street fighting war. I designed the abstract model of whole network consisting of hybrid networks. In detail, I developed the hardware diagram of major network

[3] Position data size: 50(user)*3(dimension)*10(bits/dimension)*10(transfers/sec)=15kbps
Map data size: only different information between successive samples < (320*240*24bits)/10=180kbps

elements, software diagram and protocol stack. Specifically, I emphasize on security and applications (services running on network). Lastly, I simulated the abstract model of network for packet loss performance using NS-2.

More detail simulation for delay could be further studied when we use security methods I defined. Furthermore, accurate data for modeling satellite network and ad-hoc network in simulation are highly required.

6. References

[1] NS2 Manual

[2] Andrew S. Tenenbaum, "Computer Networks, 4th ed.," Prentice Hall, 2003

[3] A. Nejat Ince, "Digital Satellite Communications Systems and Technologies," Kluwer Academic Publishers, 1992

[4] C.-K.Toh, "Ad Hoc Mobile Wireless Networks: protocols and systems," Prentice Hall, 2002

[5] P. Bhagwat et al, "Enhancing throughput over wireless LANs using Channel State Dependent Packet Scheduling," in Proc. IEEE INFOCOM'96.

[6] Saar Pilosof, Ramachandran Ramjee, Danny Raz, Yuval Shavitt, and Prasun Sinha, "Understanding TCP fairness over Wireless LAN," in Proceedings of IEEE Infocom , Apr 2003.