Analysis of OFDM in VHF/UHF tactical MANETs with SDRs

Abstract—**This report is intended as an introduction to tactical MANETs, networks which are composed of mobile nodes connected wirelessly in a self-configured, self-healing network without having a fixed infrastructure. In addition to this, Software Defined Radios (SDRs) advantages for military applications were presented. Finally, simulations were performed to analyze the feasibility of employing OFDM in this scenario, concluding that there are better solutions which are compliant with the requirements of tactical MANETs.**

Keywords—MANET, SDR, OFDM, tactical communications

I. INTRODUCTION

Tactical communications are military communications between two or more military units, including communications between different military ranks. This information is usually orders and military intelligence, which can be classified in voice, video or data.

As battlefield is constantly changing, tactical communications require accurate information, including a robust and secure link. The tactical level units are tasked with missions requiring entirely different communication systems. In the tactical communications peer-to-peer nodes must remain at top priority to provide survivable communications. On the battlefield it is essential that commanders can command and control on the move, including continuity of command and control whilst deploying from the barracks as well as whilst moving around the battle-space.

Design considerations of tactical networks depend on multiple factors like the operational scenario. However, they can be grouped in the following ones [1]:

- Mobility: problems of mobility in the operation of the network also apply to subscribers, switches, and other support equipment such as transmission equipment and generators. Equipment should be small physical size and weight, low powered consumption and reduced signaled.
- Security: as electronic warfare is evolving, communications can be affected by jammers or spoofers. The security of the network and its survivability can be ensured by encryption devices and anti-jamming techniques.
- Availability: system availability must be maintained particularly for the key network subscribers. For that, switches in the network are automatically updated as the network connectivity changes and can reroute calls via alternative paths, there are priority mechanisms and spectrum allocation must be assigned carefully.
- Flexibility and interoperability: the capability to interface to existing equipment as well communication with other services and allies is essential. Sofware Defined Radios (SDRs) play an important role in this requirement.

Due to its nature, military communications architecture must provide a mobile infrastructure to support mobile users. As commented, it provides secure digital voice and data communications in an area. Maximum area coverage and capacity is defined by the used waveforms.

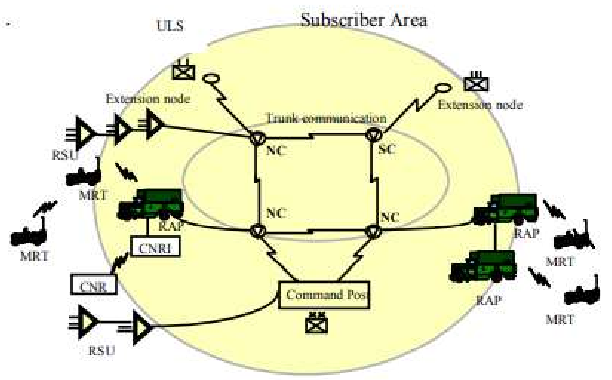


Fig. 1. *Terrestrial Communications System Architecture*

Figure 1 shows the Terrestrial Communications System block. The Extension Node (EN) units extend the switching capability of the Node Controller (NC) via VHF Line of Sight (LOS) radios. A normal NC consists of a digital automatic switch installation and an automatic radio integration interface with a manned hybrid switch and a manned radio integration capability. Routing algorithms of the switch choose a hop-by-hop path based on information about link connectivity. The simplest scheme is flooding, in which a packet is transmitted on all links from the source to neighboring nodes, which then repeat the process. Flooding is inefficient but can be the best strategy when a network topology changes rapidly. In general, network topologies vary rapidly in mobile packet radio networks, with links constantly being lost and new ones established. Therefore, the network management component needs to disseminate connectivity information more rapidly than is necessary in wired networks. [1]

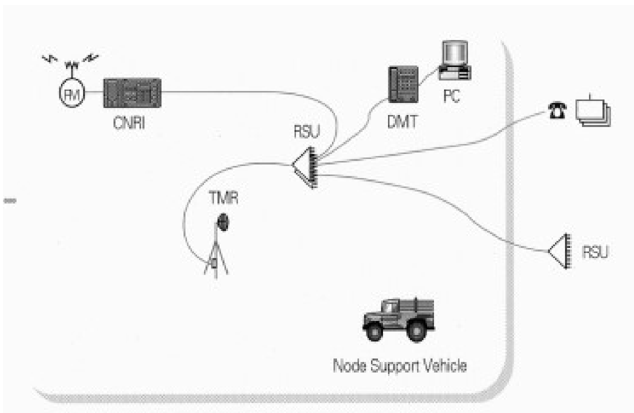


Fig. 2. *Unit Level Switch*

A typical Unit Level Switch (ULS) for small group is shown in Fig. 2. Nominal range of this equipment is 15 km depending on terrain. Communication can be achieved by sending the information from the Personal Computer (PC), which can be replaced by a SDR. This device sends the information to the Digital Multirole Terminal, which is connected to the Remote Switching Unit, terminal which acts like a router and routes the packets (which have been processed in the DMT) to the system that will send them (Tactical Microwave Radio in the figure). [1]

Previous figures showed a general overview of a classic tactical network architecture which will rely on the Mobile Ad-hoc NETwork. Everything over IP is one of the main requirements of the next generation of tactical MANETs. VHF/UHF network users (nodes) are now expecting to be able to share, in addition to voice, a variety of IP-based data services such as chat, email, file transfers and Situational Awareness (SA). This requires a system that can provide increased throughput without compromising robustness and long-range signal coverage, two important characteristics of VHF/UHF communications. For medium access, as nodes must share the radioelectric spectrum, techniques like OFDM and TDMA are used.

With the recent advances in tactical communication, MANETs are using Software Defined Radios (SDRs) which offer great flexibility and interoperability capacities. Todays SDR has a reconfigurable architecture. SDR is specifically built to have a radio platform, important to have a waveform. Waveform's expensive parts are developed in software, giving the adaptability to change the waveform inside specific limits. SDRs also implement most of the network interface functionality e.g physical layer and the data link layer in software. Unfortunately, the high level of versatility offered by SDRs does not thus incite adaptability in the MAC implementation for MANETs, so independent techniques must be used.

This report is structured as follows. After the Introduction, Tactical MANETs and Software Defined Radios will be explained. Finally, Medium Access Techniques will be considered.

II. TACTICAL MANETS

A MANET is a dynamic and self-configuring network consisting of a collection of mobile nodes connected by wireless links. As a result of this, a MANET does not need base stations or access points, as each network node can act as a whole communication entity. Each node has the information of the network and its neighbor's nodes and it has the capacity to send and receive information. Tactical MANETs are formed of broadcast radios where spectrum is shared among the users. The communication is half-duplex (a radio system can either transmit or receive but can never perform the two operations simultaneously). In addition, each node is mobile and can move in and out of the transmission range of another node. Consequently, networks may include multi-hops where each node may play the role of a relay node.

Particular to VHF/UHF tactical MANETs is the fact that nodes communicate with each other across bandwidth constrained radio links. In the VHF/UHF bands, the spectrum availability is limited. In this bandwidth limited environment, the challenge lies in providing increased capacity for the network operations while maintaining robust and long-range signal coverage.

A. Architecture

In a MANET, each node is composed of many devices. It includes a network router to which one or multiple LANs of possibly different security classifications are connected. The LANs host the various IP-based applications and data services used during operations. The network router is connected to a network radio device. The network radio device is typically made of two components: a Radio Interface Unit (RIU) and the RF unit of the radio. The RIU interfaces between the IP data router and the RF unit. The RIU essentially implements the protocol stack that provides IP data transfer in a multiple-node, multiple-hop dynamic network. [3]

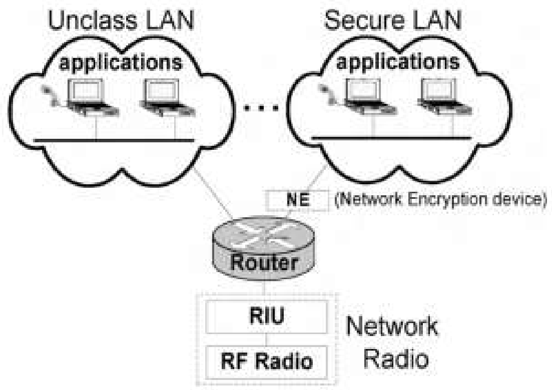


Fig. 3. *Tactical MANET node architecture*

RIU

The Radio Interface Unit implements an interface between the IP data router and the RF unit, including protocol layers to provide services. It performs the translation of the information between the network layer and the link layer.Link layer is responsible of sending the information to the MAC layer, performs the Quality of Service (QoS) strategy and packet control. MAC layer coordinates transmissions and PHY layer connects the upper layers with the RF unit to send the signal. [3]

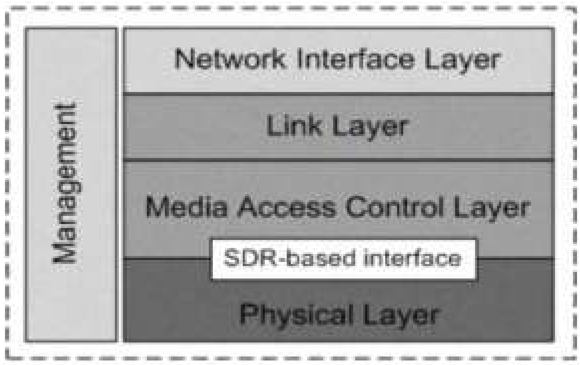


Fig. 4. *RIU protocol stack*

B. Networking Applications

- Situational Awareness: as MANET is dynamic, it is necessary to transmit the location and other situational information. It does not need high data rates as it is usually simple information regarding to position, location, and tracking (PLT), being especially important what is known as Blue Force Tracking (BFT).

- Short Payload Messaging: it is used for linking various teams and team members for silent, concise and accurate communications. The short messages can be free-hand input by users or predefined as part of mission profile. [2]

C. Payload Characteristics

- Voice/Data Simultaneity: actual radios transmit not only voice, but also data information. As a result, both services must be supported simultaneously. For direct point-to-point voice communication between MANET nodes voice communications can be supported by legacy waveforms in non-packetized mode (CNR voice). To support multi-hop voice, the voice needs to be packetized, and the number of hops needs to be limited to maintain good voice quality. Voice and data transmission can share the access to RF medium arbitrated by a MAC protocol, such as CSMA MAC.

- Multicasting/Broadcasting: communications can be point to point or point to multipoint. In the last group there are tow more options, broadcast to the whole network or multicast to the subscribed nodes.

D. Network Topology and Routing

As it is shown in Figure 3, the requirements of tactical operations, the use cases, and the mobility and density of the nodes all affect the network topology. Every node in the network must be able to communicate with the rest of the nodes, in a hop or using the other nodes as a relay (multi-hop).

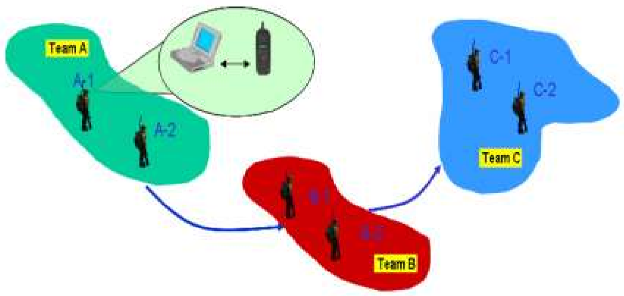


Fig. 5. *Tactical MANET Configuration Example*

- Node Mobility and Density: a tactical MANET can contain motorized nodes with a high degree of mobility. The number of nodes in a MANET is usually less than 16.

- Gateway Support: multiple MANETs can be formed over different RF channels and linked together by gateways. Gateways can also provide SATCOM reach back or fixed network connectivity for a tactical MANET. Depending on the network operational requirements, we can differentiate between stand-alone networks (nodes has the same channel and waveform), stub network (one gateway connects the stub MANET to another MANET or fixed network) and transit networks (it connects to multiple external networks through multiple gateways). [2]

III. Software Defined Radios

Implementation of SDRs occurred due to the necessity of communicating different type radio systems (more than 2 different waveforms). Software-defined radio (SDR), also called software radio (SR), refers to wireless communication in which the transmitter modulation is generated or defined by a computer. The receiver then also uses a computer to recover the signal intelligence. SDR is an enabling technology that is useful in a wide range of areas within wireless systems. The primary goal of SDR is to replace as many analog components and hardwired digital VLSI devices of the transceiver as possible with programmable devices. These include the air interface, modulation and coding schemes, analog-to-digital converter (ADC), and digital-to-analog converter (DAC).

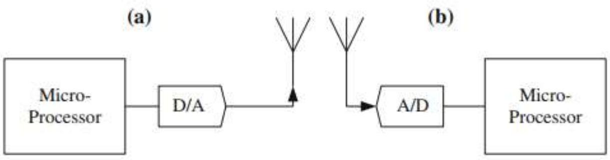


Fig. 6. *Ideal software-defined radio: (a) transmitter, (b) receiver*

The ideal software-defined radio is shown in Figure 6: the user data is mapped to the desired waveform in the microprocessor, the digital samples are then converted directly into an RF signal and sent to the antenna, the transmitted signal enters the receiver at the antenna, is sampled and digitized, and finally processed in real time by a general purpose processor. The ideal SDR hardware should support any waveform at any carrier frequency and any bandwidth. [4]

A. Advantages

- Interoperability: an SDR can seamlessly communicate with multiple incompatible radios or act as a bridge between them. Different branches of the military and law enforcement use dozens of incompatible radios, hindering communication during joint operations. A single multi-channel and multi-standard SDR can act as a translator for all the different radios.

- Flexibility: an SDR can adapt the waveform to maximize a key metric. By choosing the appropriate waveform for every scenario, the radios can provide a better user experience.

- Opportunistic frequency reuse (cognitive radio.): an SDR can take advantage of underutilized spectrum. This technique has the potential to dramatically increase the amount of available spectrum.

- Reduced obsolescence: an SDR can be upgraded in the field to support the latest communications standards. This capability is especially important to radios with long life cycles such as those in military and aerospace applications.

- Lower cost: an SDR can be adapted for use in multiple markets and for multiple applications. Economies of scale come into play to reduce the cost of each device.

- Research and development: an SDR can be used to implement many different waveforms for real-time performance analysis. Large trade-space studies can be conducted much faster (and often with higher fidelity) than through simulations.

B. Signal Processing Devices

As a SDR implements at least some of the physical layer functionalities in software, the use of different type of processors is needed: [4]

- General Purpose Processor (GPP): it is a typical microprocessor optimized to handle the widest possible range of applications. This makes them suitable for implementing much of the SDR functionality, starting with the physical layer DSP and ending with the protocol and network stacks. GPPs provide the easiest development environment and highest developer productivity.
- Digital Signal Processor (DSP): it is a microprocessor that is optimized for number crunching. The main advantage of DSPs over GPPs is in power consumption per operation. But they are not well suited for control code such as the protocol and network stack. A typical SDR would pair a DSP with a GPP to implement the network stack. DSPs are used extensively in software-defined cellular base stations and in radios that require low power and have modest data rate requirements.
- Field Programmable Gate Array (FPGA): it is a microchip that is designed to be configured by the user after manufacture. FPGAs contain programmable logic components called ''logic blocks'' and reconfigurable interconnect to ''wire'' the blocks together. The interconnect can be used to implement the desired functionality. However, the overhead of all the wiring and switches makes FPGAs consume significantly more power than an equivalent single function design. Designs implemented on an FPGA also execute a lot slower than an equivalent single-function design.

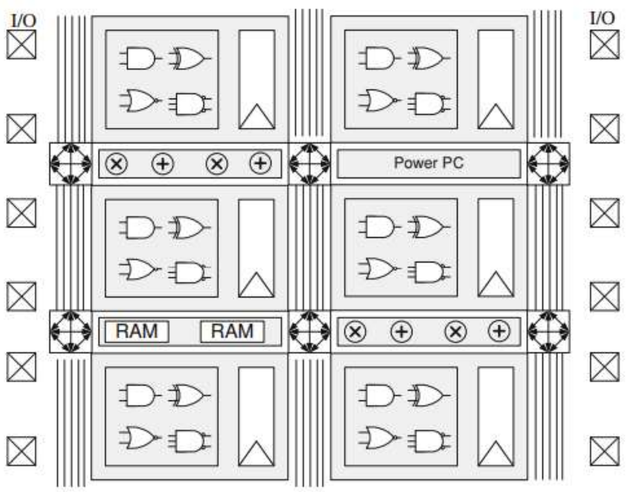


Fig. 7. *Conceptual block diagram of an FPGA, note the programmable interconnect using cross-bar connections*

IV. OFDM IN MANETs

OFDM is a modulation technique as well as multiplexing technique as it is divide a single high data rate stream into a number of lower rate streams that are data transmitted simultaneous over some narrow sub channel. OFDM technique offering better use of ad hoc network like intersymbol interference (ISI), OFDM avoids this problem by sending many low speed transmissions simultaneously and increase the network throughput. [5]

In OFDM, the sub carrier frequencies are chosen so that the sub carriers are orthogonal to each other. This greatly simplifies the design of both the transmitter and the receiver. The orthogonality allows high spectral efficiency with a total symbol rate near the Nyquist rate for the equivalent baseband signal. It reduces equalization complexity by implementing with Inverse Fast Fourier Transform (IFFT) at the transmitter and Fast Fourier Transform (FFT) at the receiver that converts the wide band signal affected by frequency selective fading into N narrowband flat fading signals. The beneficial since OFDM enables support of more antennas and large band widths since it simplifies equalization dramatically in MIMO system. [5]

A. Simulations Architecture

In this section, the feasibility of OFDM in MANETs is proven. For that, it was implemented an adaptative algorithm where, depending on the OFDM symbol size (number of subcarriers), number of OFDM symbols and modulation, the Bit Error Rate (BER) is computed depending on the Signal to Noise Ratio (SNR).

In fact, as military deployments occur in conflictive areas, effects such as jammers (intentional or not) must be considered, so what we call SNR is actually the Signal to Interference and Noise Ratio (SINR), which includes additional interferences in addition to the typical noise power. For simplicity, jammers will not be directly simulated but will be considered by reducing the SINR to values which will be around 5-10 dB.

The simulated scenario consists of a simple OFDM transmitter and receiver, where a random signal is generated, modulated, and transmitted after IFFT is performed and Cyclic Prefix (CP) is added. Then it passes through a white gaussian noise channel, CP is removed, FFT is performed and signal is demodulated. BER is computed by comparing the transmitted and received symbols.

B. Results

As you can see in Table 1, simulations show that for a SINR = 5 dB, BER value is ~10^{-2}, value which is insufficient for having trustable communications, moreover in tactical communications where robustness and reliability are strict requirements.

On the other hand, we can see that as the modulation order is increased, for SINR values higher than 5 dB the BER not only is nor reduced, but also it experiments an increase, allowing a higher data rate.

Finally, as the number of subcarriers is increased, BER values are better for SINR values greater than 5 dB.

Cyclic Prefix value was set to be fixed as in VHF and UHF communications bandwidth is limited and usually have values from 25 kHz (for narrow-band communications) to 1-4 MHz (for wide-band communications).

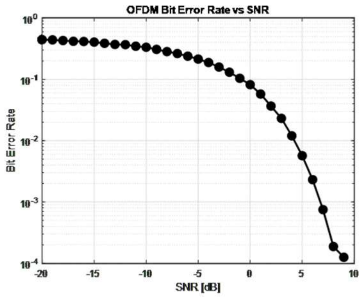
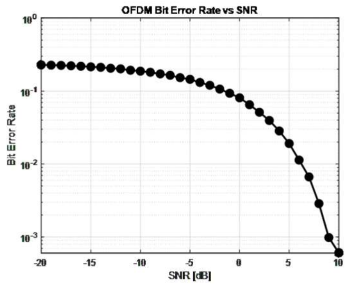
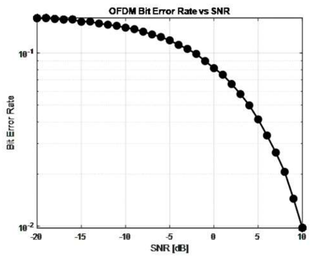
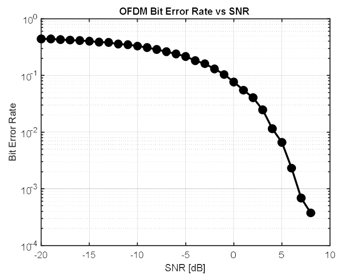
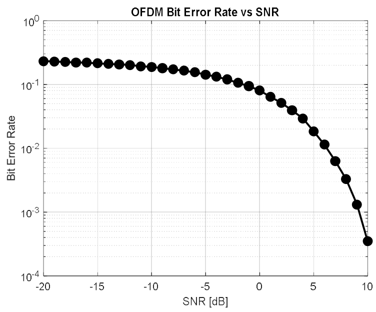
Number of subcarriers	Modulation order	BER vs SNR
16	2	
16	4	
16	8	
32	2	
32	4	

Table 1. Results of the simulations when number of carriers and modulation order values are changed

V. CONCLUSION

In this report, a theoretical explanation of MANETs in tactical communications was given, focusing on its hard requirements in terms of robustness and reliability. SDRs were also explained, as their use has experienced a huge increment thanks to their flexibility and interoperability.

Finally, some simulations were performed to analyze the impact of using OFDM in this networks, concluding that, despite its advantages for communications with high SNR and bandwidth, their use for military applications in contested scenarios might not be the best option.

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