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An Overview of MANET Technologies

Advantages and Disadvantages in the Military

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This Food for Thought paper is a document that gives an initial reflection on the theme. The content is not reflecting the positions of the member states but consists of elements that can initiate and feed the discussions and analyses in the domain of the theme. All our studies are available on www.finabel.org

DIRECTOR'S EDITORIAL

The world of telecommunications has witnessed several evolutions in the last decade, from the broad diffusion of 4G to the development and distribution of 5G. In parallel, the role of China in the dissemination of this late technology has prompted several western states to pursue their own hardware for it. At the same time, the conflicts in Yemen, Afghanistan, the war against the Islamic State, and finally, the Russo-Ukrainian war reminded us how wars are not something that belongs to the past. We can see how this conflict highlighted the importance of having interoperable and up-to-date capabilities in the land forces. As the Russian first attempt at a full-scale invasion failed, our attention should be drawn to how important planning, but more importantly, communication and coordination are on today's battlefields. Therefore, this paper aims to explain how MANETs, a specific tool for telecommunications work, pointing out also its most recent 5G upgrade. This study draws attention to how this technology offers an upper hand for telecommunications in adverse conditions but also reminds their weaknesses in a guide useful for whom would like to understand MANETs better. Finally, it undelights their potential for implementation in situations of emergency or when the events have a particularly challenging turn.

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TABLE OF CONTENTS

INTRODUCTION

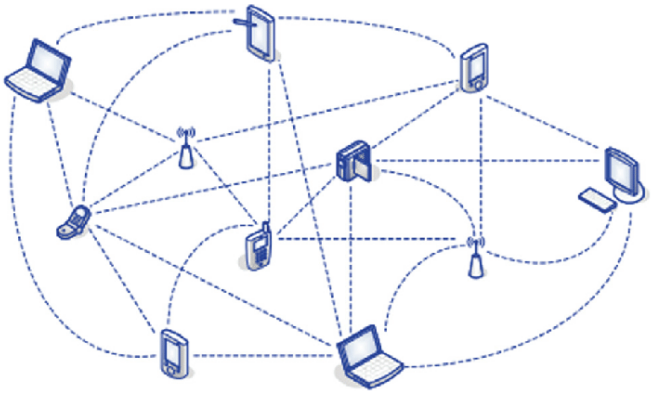
Mobile Ad Hoc Networks, also known as MANETs, are self-configuring networks of wireless devices whose applicability ranges from civilian and commercial uses to highly tactical military strategies. The variety of MANETs characteristics and typologies, together with their significant usage adaptability, make these technologies particularly advantageous when deployed in critical contexts. More specifically, these types of technologies are expected to be increasingly relevant for distant communication needs, and their role in military tactics could be crucial when adopted in contemporary battlefield. Nevertheless, as it will be discussed, the adoption of MANETs brings with it definitive opportunities as well as critical challenges that still need to be addressed. With the aim of analysing MANETs' benefits and structural deficiencies, with a particular focus on their military deployment and impact, this paper will be structured as follows. The first two paragraphs will be dedicated to presenting the main MANETs technical characteristics by highlighting how their structural features are perfectly suitable for military communication needs. Moreover, in the second paragraph, the paper will provide a historical overview of MANETs technological development. Following these first sections, we will introduce the spectrum of MANET applications, focusing on comparing the different typologies currently available and their leading industrial producers. Finally, the last section will specifically deepen the study of the advantages and disadvantages of MANETs applications.

MANET's Main Characteristics

MANETs are groups of mobile devices that can provide a communication network without an existing fixed infrastructure. They can otherwise be defined as a collection of mobile nodes (i.e. devices) capable of forming temporary and flexible communication networks without the support of a centralised control administration or standard support devices, as they are required in traditional networks. More in detail, a Mobile Ad Hoc Network is a network in which each node is willing to receive and forward data to other nodes. Therefore, due to its decentralised nature, each node of the network works as both host and router, as an endpoint and as a rely at once. This process of receiving and forwarding data is eventually made dynamically based on the network connectivity (Okeke and Nwabueze, 2010). Examples of MANET technologies are laptops, radios, mobiles or specially equipped vehicles, WI-FI[1] nets, and Bluetooth technologies. A typical MANET architecture is shown in the following scheme:

Distinctively from a standard LAN[2], one of the MANETs' main characteristics is that they can decide whether to communicate through

1. "Wi-Fi is a wireless networking technology that allows devices such as computers (laptops and desktops), mobile devices (smartphones and wearables), and other equipment (printers and video cameras) to interface with the Internet" (Cisco).
2. A local area network (LAN) is a collection of devices connected together in one physical location, such as a building, office, or home. A LAN can be small or large, ranging from a home network with one user to an enterprise network with thousands of users and devices in an office or school. Regardless of size, a LAN's single defining characteristic is that it connects devices that are in a single, limited area." (Cisco).



Source: https://www.researchgate.net/figure/Mobile-Ad-Hoc-Network-architecture-MANET_fig1_316291648

Fig. 1: Architecture of a mobile ad hoc network (MANET).
Authors: Dr. Asha Shripad Ambhaikar and G. Mahadevan. A combined video packet transmission scheme to enhance cross-layer to support QoS for MANET - Scientific Figure on ResearchGate.

the internet or to use radio and electromagnetic signals, depending on devices' connectivity capacities and net availability and reliability in each operational context. Ad hoc network that links mobile nodes and fixed Internet-gateway nodes are called Internet Based Mobile Ad Hoc Network (iMANETs). Furthermore, thanks to their link adaptation, when using radio signals, a particular MANET radio may communicate with other devices using different data rates[3] depending on the actual distance between them. For instance, radios can use a data rate of over 50 Mbps to connect with close devices while using a speed of only 2 Mbps to provide a robust link to more remote radios (Silvus Technologies). Having high potential data burst rates eventually reduces airtime consumption in short-range communications.

Moreover, MANET's fundamental feature remains independency. Indeed, MANET is said to be independent of other means because there is no need for a fixed infrastructure providing inputs for its connected devices. Instead, each node is completely autonomous in its behaviour. Devices communicate directly with their peers by forming chains of transceivers to deliver information. Provided that each device is independent of the others, the network has hence the capacity to reconfigure itself erratically and in a real-time manner, depending on how, where, and when other nodes join or leave the network. This is why the MANET range is extendable every time there is a new mobile on the ground or in the sky, passing in the proximity of other active devices. Without a permanent physical infrastructure, actors on the field, such as soldiers on a battlefield, can impact the network only by moving themselves together with their devices. Indeed, networking nodes are driven by tactical routers allowing them to automatically discover the optimum route of communication traffic in all possible directions.

Within a MANET, all nodes move in a symmetric environment, meaning that networks have the same standards of communication and minimum characteristics. This characteristic provides MANET with a de facto extensive ease of connection. To provide a

3. Although the terms "data rates" and "bandwidth" are generally used interchangeably, they refer to two different concepts. On the one hand, data rate is defined as the number of bits transmitted through a channel of communication per unit of time. On the other hand, bandwidth or frequency, refers to the frequency rate a component can receive or transmit data.

concrete example, one of the most common models of MANET technologies is the Bluetooth in our mobile phones. Once activated, Bluetooth can locate other active signals, and it is eventually possible for the device's owner to create a network and share information via Bluetooth with others. If this is a particularly trivial example, the basic functioning of every advanced mobile ad hoc network is nearly similar.

Another interesting and advanced characteristic of mobile networks is the so-called "**multi-hop**" feature. When a source node must connect with a destination node to deliver a message, if the latter is out of the available signal range, the MANET can redirect such message to other transition nodes. Therefore, multiple close nodes are configurated to allow communications to pass through and permit their final delivery to a specific receiver (multi-hop routing). Moreover, by creating redundant paths, multi-hop routing increases the network resilience in case of one node failure (Baker, 2015).

Accordingly, MANET allows information sharing regardless of geographic location or the remoteness of infrastructure (TRIAD, n.d.). This capability is fundamental in military employment since it allows land, aerial, and marine forces to ensure their communication with troops, vehicles and headquarters even in complex contexts. Minimal configuration needs and rapid deployment structures make ad hoc networks suitable for emergency situations or military operations (Okeke and Nwabueze, 2010).

Nevertheless, considering this dynamic architecture, a few technical factors must be considered. First, constant reconfiguration efforts led MANET to have limited battery and memory power. Consequently, devices in ad hoc networks risk being affected by excessive energy consumption. Moreover, being each node independent yet fundamental in a multi-hop communication scheme, each MANET component can potentially be a victim of cyber-attacks. These factors represent two of the most relevant technical challenges for deploying ad hoc network technologies (Madhavi and Muralidhar, 2017).

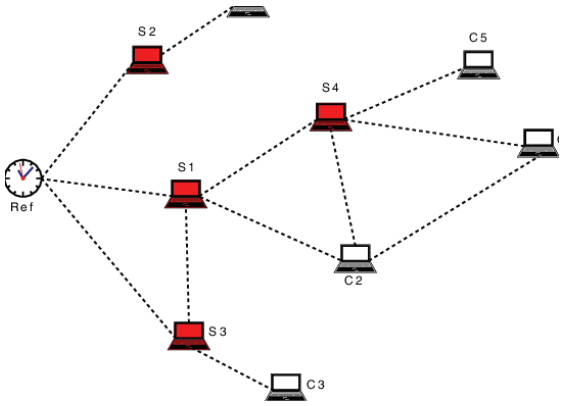


Fig. 2: An example of a multi-hop network.
Authors: Wehbi, Bachar & Laouiti, Anis & Cavalli, Ana. Efficient time synchronization mechanism for multi-hop wireless networks - Scientific figure on ResearchGate.

Source: https://www.researchgate.net/figure/A-multi-hop-network-example_fig1_221576744

When outlining the development of Mobile Ad Hoc Networks, experts in the field distinguish three different generations. The first generation appeared in the 1970s when the so-called Packet Radio Network (PRNET) was first developed by the American Defense Advanced Research Project Agency (DARPA). The agency researched the use of packet-switched radio communication and proved its reliability in allowing communication between computers and urbanized PRNET for multiple access and distance routing (Kumar and Mishra, 2012).

During the 80s, PRNET evolved into the Survivable Adaptive Radio Network (SURAN). The new network design benefited the radio performance by reducing their size and making them cheaper and more efficient in terms of energy consumption. Moreover, SURAN presented improved scalability of algorithms, meaning that it had an increased capacity to effectively utilise an increasing number of processors. Eventually, this increased resilience capabilities to face electronic attacks (Sherlock, 2021).

In the same period, the US Department of Defence (DOD) funded two research and development programmes: Globe Mobile Information System (GloMo) and Near-Term Digital Radio (NTDR) (Nazi and Asif Habib, 2022). Such programmes can be considered the first concrete step towards the development of modern MANET since they welcomed the second generation of ad hoc networks. Indeed, thanks to the funding of such programmes, the architecture of self-organising and self-healing networks were eventually developed.

Lastly, the third generation took life during the 90s, after the advent of laptops, open-source software, and new communication equipment. More in detail, the Internet Engineering Task Force (IETF), an international community of engineers, administrators, and researchers, worked on the standardisation of routing protocols and introduced the term "MANET". The task force's work permitted the rise of technologies such as Bluetooth and the WLAN[4].

Last Developments - the 5th Generation Data Networks

Among the technologies that MANETs can rely on there are mobile data networks. As of 2022, the latest update for this kind of network is the fifth generation, known as 5G (Parcu, Innocenti and Carrozza, 2022). Compared to the previous generation (4G), 5G offers an increased speed in data transfer and incremental, disruptive, and radical changes in the technology (Suryanegara, 2016). It is said to carry innovation in several sectors (Parcu, Innocenti and Carrozza, 2022). However, for this paper, it is essential to note the pivotal role it has and will have for telecommunica-

4. A **wireless local area network (WLAN)** is a wireless computer networks that connects two or more devices using wireless communication to form a LAN. A WLAN should not be confused with a WI-FI technologies which is only one of the possibile standards WLAN can use. A WLAN (the network itself) can use different frequencies and configurations. In order to connect to a WLAN, devices can be set up to work with different frequencies or to conform to established standards. WI-FI is a particular form of communication mode supporting a IEEE 802.11 standard. This means that devices provided with WI-FI technologies communicate at the same frequency.

tion technologies (Cave, 2018).
Besides the capabilities of the new generation of data networks, it can be noted how the frequencies between the two highly differ. While 4G works with frequency bands below 6GHz (Goss, 2022), other "existing mobile spectrum lies uniformly below 6 GHz, and mostly below 3 GHz" (Cave, 2018). Therefore, for some years, it has been confirmed that MANETs do not rely on below-6GHz bands anymore, thanks to the mobile applications of 5G (Dua, Amit, Neeraj Kumar, and Seema Bawa, 2015). As explained above, MANETs are particular wireless networks that self-organise and auto-connect in a decentralised system. In this system, every device can move freely from one location to another in any direction without compromising data transmission. This is because of the interoperability of the divides that use the same standards. Because of this very nature of MANETs, they are fundamental for developing the contemporary Internet of Things (IoT) (Archana, Dineshkumar and Uma, 2020). Today's smart devices, smart home applications and cars use similar technology to the neighbour smart device, forwarding the data to the next one, but also relying on a Cloud MANET framework, "composed of IoT, cloud computing and MANET" (Archana, Dineshkumar and Uma, 2020). This highlights the increasing importance of both 5G and MANETs in today's world. In their military application, utilising this kind of MANETs could provide both opportunities and challenges. While the increased band implies a broader range of available communications, the centralisation of the computing of information creates a 'central node' which changes the nature of this technology, going beyond what a MANET is. At the same time, the high broadband used allows for greater speeds for the transit of data, which need frequent repetitions because of the limited distance they can travel without package loss.

MANET Applications

MANET is beneficial in different environments and circumstances. Their application ranges from entirely civilian to uses in military operations. Current applications include the field of military and defence, rescue operations, new smart cities services, business activities or other civilian uses.
On the one hand, for what concerns civilian employment, MANET is mainly deployed as a tool for collaborative work, enhancing collaborative computing, project information sharing and allowing outside meetings and conferences. Moreover, as already highlighted, MANETs are essential for people's multimedia sharing via Bluetooth, Wifi, and others.
On the other hand, in military or military-led operations, ad hoc networks allow forces on the ground, sea and air to take advantage of the technology to maintain strong information exchange networks between soldiers, moving assets and headquarters. As clarified by Dave Barker on Extreme Engineering Solutions, once on the battlefield, troops and military vehicles need to communicate, despite the lack of direct access to the central network (2015). MANET's characteristics, including their decentralised nature, size, and weight optimisation, respond to such needs. They appear essential for guaranteeing in-

formation exchange in case of infrastructure failure or in the context of emergency rescue operations when traditional communication lines can be damaged or disrupted.

Other MANET Typologies

Over the years, ad hoc communication technologies have been classified into different typologies depending on their specific aim and configuration. Among the types of networks, there are Vehicular ad hoc networks (VANET), Intelligent Vehicular ad hoc networks (InVANET), Services and Protocol for Advanced Networks (SPANs), Flying ad hoc networks (FANETs), and Piconet.

- VANETs are wireless technologies used for communication between moving vehicles and roadside nodes. Thanks to the increasing number of vehicles equipped with computing technologies and wireless devices, intervehicle communication is becoming a promising field of standardisation and technological development (Badis and Rachedi, 2015). VANETs support many applications, including multi-hop dissemination over vast distances. VANET network operates without any legacy client and fixed communication server. As in a classical MANET, each vehicle equipped with a VANET device will be a node in the ad hoc network and can receive and relay others' messages through the wireless network (Okeke and Nwabueze, 2010). One of the main differences between VANET and MANET is that vehicles network tends to move in a more organised fashion than in MANET nodes.
- A further enhancement of classical VANET is the InVANETs. Intelligent vehicular ad-hoc networks integrate multiple ad-hoc networking technologies, ie. Wifi, Bluetooth or IRA to increase the level of accuracy of the message. This kind of technology is integrated, for instance, into unmanned cars to increase their integrated safety measures or to react to city traffic most efficiently.
- SPANs are essential communication technologies enhancing Bluetooth or Internet configurations. They can influence the hardware to create a peer-to-peer network without relying on cellular networks or other traditional infrastructures such as wireless access points. Differently from other networks, working in a peer-to-peer modality, each node in a SPAN can join and leave the net at any time without destroying the net.
- FANETS is the ad hoc network employed for aerial communication. It is made of a group of UAVs communicating with each other without needing an access point. However, different from grounded-MANET devices, at least one FANET node must be connected to a GCS or satellite. This network typology differs from MANET's variety in conception and design (connectivity, quality of services, sensor types, node movement features, data delivery, service discovery, etc.). This means that MANET architecture is employed but adapted to the UAV network design (Chriki et al., 2018).
- A Piconet is a particular ad hoc network that links wireless device groups using Bluetooth technology protocols. In this

network, the primary device, known as *master,* provides synchronisation patterns for the other connected ones (*slaves*). Single piconets allow a limited number of devices to join the network, but non-synchronised piconets can communicate. A slave and a master unit can establish new connections and eventually enter other piconets. Due to its Bluetooth-based architecture, piconets are short-range wireless standards inserted in broad-range environments.

THE INDUSTRY: LEADING COMPANIES AND INTRODUCTION OF THE COMPARISON

Main companies:

Mobile Ad Hoc Networks (MANETs) are currently produced by a certain number of companies specialised in the military domain. It is possible to identify Silvus Technologies, Bittium, Thales or even Persistent Systems, for instance.

Silvius Technologies:

Silvus Technologies is an American private company founded in 2004 in Los Angeles. Its main mission is to put forward the benefits of MIMO[5] communication technology to transmit high-fidelity video, voice, and data in difficult conditions. The company is notably working alongside various experts to pursue government-funded research and development opportunities, tackling Non-Line-of-Sight (NLOS) propagation, interference, high mobility and spectrum congestion. Until now, Silvus Technologies managed to execute more than 56-million-dollar contracts effectively. As of 2011, the company began to put into practice its expertise in terms of MIMO communication to notably develop a commercial product line called StreamCaster family of MANET radios. The company is since then working on improving its products regarding weight, size, power, cost and focusing on developing next-generation features and capabilities. (Silvus Technologies, n.d.)

More specifically, the main subject of our analysis, Mobile Ad Hoc Networks, the company is collaborating with Information Assurance Specialists (IAS) to support the US Army's approach to MANETS. (Silvus Technologies, 2019) In 2020, the US Army notably concluded a contract with Silvus Technologies to acquire its StreamCaster MANET Radio. (Ball, 2020). The device in question is a small, lightweight, single-channel radio system. It can support a network of 140 nodes at the company level at a bandwidth of 1.25 MHz at a range of more than 1 km. The radio system is also equipped with interference avoidance capabilities, set to withstand network traffic in an electronic warfare interference environment. (Cooper, 2022).

5. MIMO stands for Multiple-In Multiple-Out. MIMO devices are designed so that "when a packet is transmitted into the channel it is transmitted on more than one antenna and when it comes out of the channel it is received on multiple antennas. This is in contrast to a Single-In Single-Out system with one antenna on both ends of the link, or a SIMO system which would include some types of radios that use diversity combining at the receiving end but still transmit over only a single antenna"(Silvus Technologies, 2022).

Bittium:

Bittium is another company that we can cite as a producer of MANETs. Created in 1985, Bittium is an engineering Finish company based in Oulu, Finland. Bittium is dedicated to developing secure communication and connectivity solutions. Its main customers are related to the sectors of telecommunication, the Internet of Things, and defence industries. (Bittium, n.d.)

To meet the needs required for more flexibility in terms of operational and tactical communication for troops on the field, the company developed various mobile ad-hoc networking solutions. It is possible to identify the Bittium TAC WIN RH-I radio unit, the Bittium Tough SDR Vehicular, and the Bittium Tough SDR Handheld.

- The Bittium TAC WIN RH-I radio unit: This particular MANET is interoperable with various infrastructures, whether wireline or wireless. It allows the creation of an independent IP network which can enable support to command and control data transmission during military operations.
- The Bittium Tough SDR Vehicular: The device is « a 2-channel software-defined radio for tracked & wheeled vehicles and weapon & sensor platforms ». It helps generate and share real-time situational awareness, which constitutes an asset for the troops' performances and effectiveness based on up-to-date situational awareness and more reliable connections.
- The Bittium Tough SDR Handheld is a tactical radio for dismounted soldiers, providing a wide frequency range of 30-2500 MHz. It is said by the company to provide broadband data transfer and voice to mobile troops on the field.

Persistent Systems:

Persistent Systems is a US-based company founded by Dr Herbert B. Rubens and Dr David Holmer. It is specialised explicitly in mobile ad hoc networking (MANET). The company has been producing and commercialising its MANETs for over a decade in the Defence and Industrial sectors.

Persistent Systems' products featuring MANET technology include the MPU5, the Embedded module; GVR5; the Dual Push to Talk (PTT), the Rugged Display and Controller (RDC); the Multi-Band Tracking Antenna; the Integrated Antenna Series Radio Modules; Android Kit.

Thales:

Headquartered in Paris, Thales is a French multinational company founded in 2000 and focuses on the fields of Big Data, artificial intelligence, connectivity, cybersecurity and quantum technology. The company is set to provide various solutions, services and products to its customers coming from the defence, aeronautics, space, transportation and digital identity and security markets. It contributed to the defence and security sectors, for example, by equipping more than 50 land forces and over 40 navies or selling over 1200 air defence radars to 26 countries. (Thales, n.d.).

Thales's Javelin Combat Net Radio is part of its tactical communication products, which

US soldiers notably use. The company started producing them as part of « US Army's Integrated Tactical Network and Non-Developmental Item approach to Capability Set fielding's ». Thales presents the device as a cost-effective, small form factor, rugged and single-channel MANET radio which is allowing tactical command and control communication. (Thales, 2021)

ADVANTAGES AND DISADVANTAGES OF MANETS

The open-source literature on MANETs applications in the military is scarce. However, we can identify key advantages and limitations based on what is available online and the nature of MANETs in general. To present the findings and our consideration on the matter, this section will first present the main advantages and then the disadvantages or challenges of MANET applications in the military field.

Advantages for the military

The implementation of MANETs into military communication systems allows for several advantages. This section will provide the main benefits of this choice. **First**, because of their very nature, MANETs provide a communication network between troops, command centres and even the population without needing a precedently built communication infrastructure. This characteristic is a derivative of the fact that MANETs do not have a central node they depend for communications (Chitkara and Ahmad, 2014). The main advantages of this are that the communication network becomes more resilient to physical disruption such as kinetic bombing and hacking attempts. Consequently, not only in case of war but also in case of human or natural-made disasters in which the telecommunications infrastructure appears damaged or destroyed, MANETs are essential for guaranteeing information exchange- The same remains valid in emergency rescue operations context when traditional communication lines can be damaged or disrupted. In this context, MANETs can remain operational in case of failure of one of the nodes (Baker, 2015).

Second, MANETs permit flexibility in the type of communication one wants to use, whether through the internet or radio and electromagnetic signals. Although, the choice is often depending on devices' connectivity capacities and net availability and reliability in each operational context.

Third, because of the diverse type of communications, MANETs can operate using different data rates, as seen. This allows adapting both the strengths and speed at which data are transferred, and the distance covered between each node of the network. For this reason, a MANET network is of great utility for an army, particularly in missions abroad, since it allows information sharing regardless of geographic location or the remoteness of infrastructure (TRIAD, n.d.).

Fourth, this technology allows 5G upgradability. A MANET in 5G will be a radio sys-

tem aimed at extremely high data rate, low latency, lower energy, and cost. To support this, routing protocols in the MANET must be flexible, energy-efficient and high performance achievable. (Archana, Dineshkumar and Uma, 2020)

Disadvantages and challenges

The implementation of MANETs is not, however, free from challenges or disadvantages. These will be explored in this section. Notably, most challenges within this technology are design related. In fact, MANET networks inherit several problems present in wireless networks. They are not protected from outside or malicious signals as it is straightforward for an unwanted user to join the network when there is not a central node or infrastructure that provides checking on the network. The weakness of the signal, most commonly in the fringes of the network, can cause the network to suffer from time-varying[6] and asymmetric propagation properties[7]. Moreover, some phenomena, such as the hidden terminal and exposed terminal, can occur[8]. All in all, this means that wireless signals are more unreliable compared to wired communications.

Their 'anarchic' nature makes them weaker against flaws, which are indeed more probable and difficult to identify. Since there is no central node or administration, it is difficult to detect what error occurred and in what node of the network, together with their reason. Furthermore, as nodes can freely arrange themselves, the information route is changeable and more subject to network partition[9] and packet losses[10]. For the same reason, a network should be able to support a varying number of devices; because of the intensification of the network, each device must be able to support scalability.

As the different nodes are interoperable but not necessarily the same devices, the network is continuously mutating asymmetrically. This means there are different transmission and receiving capabilities within the same network.

Internet-based connections rely on TCP/IP and UDP/IP standard protocols[11][12]. Therefore, allow for encrypted communications and for non-encrypted ones, which are extremely dangerous in the military setting. Similarly, the signal can be intercepted or detected since "the wireless medium has neither absolute nor readily observable boundaries outside of which stations are known to be unable to receive network frames" (Chitkara and Ahmad, 2014).

Finally, the 5G implementation in MANETs has its specific problematics. While support-

6. **A time-variant** system is a system whose output response depends on moment of observation as well as moment of input signal application. In other words, a time delay or time advance of input not only shifts the output signal in time but also changes other parameters and behaviour. In MANETs this happens because several devices that serve as nodes are moving, it being carried by a person or a vehicle.
7. Having **asymmetric propagation properties** means having the signal not spread evenly within the network. In MANETs this happens because the devices within the network have different properties, therefore, they have different capabilities in terms of signal propagation for what regards its strengths, speed and distance.
8. In wireless LANs, "the **hidden terminal problem** is a transmission problem that arises when two or more stations who are out of range of each other transmit simultaneously to a common recipient. This is prevalent in decentralised systems" such as MANETs "where there aren't any entity for controlling transmissions. This occurs when a station is visible from a wireless access point (AP), but is hidden from other stations that communicate with the AP. (The Hidden Terminal Problem, n.d.)
9. A **network partition** is "a network failure that causes the members to split into multiple groups such that a member in a group cannot communicate with members in other groups. In a partition scenario, all sides of the original cluster operate independently assuming members in the other sides are failed. Network partitioning is also called as Split-Brain Syndrome" (Network Partitioning, n.d.).
10. A **Packet Loss** is a set of data that is lost in between communication devices. This information can be lost completely or intercepted but does not necessarily give up information, this should be further researched.
11. Protocols are sets of rules for message formats and procedures that allow machines and application programs to exchange information. These rules must be followed by each machine involved in the communication in order for the receiving host to be able to understand the message (IBM Docs, 2022).
12. **TCP/IP and UDP/IP protocols**, User Datagram Protocol (UDP) or the Transmission Control Protocol (TCP), receive the data from the application, divide it into smaller pieces called packets, add a destination address, and then pass the packets along to the next protocol layer, the Internet Network layer. The Internet Network layer encloses the packet in an Internet Protocol (IP) datagram, puts in the datagram header and trailer, decides where to send the datagram (either directly to a destination or else to a gateway), and passes the datagram on to the Network Interface layer. The Network Interface layer accepts IP datagrams and transmits them as frames over a specific network hardware (IBM Docs, 2022).

ing wider bandwidth and higher speeds, they are limited in their transmission range and by the need for transmitting narrow beams to cover more considerable distances (Archana, Dineshkumar and Uma, 2020). In addition, the 5G sector is heavily government-controlled; therefore, implementations might be slower if possible. Particularly in Europe, "a 5G action plan heavily linked to the Digital Single Market" (Cave, 2018).

Conclusion

The use of MANETs in the military field is nothing new but, at the same time, not completely developed. This research found, however, great difficulties in finding material regarding this specific application.

MANETs production is framed by several leading companies in the military field, such as Silvus Technologies, Persistent Systems, Bittium, and Thales. Despite the given information related to their MANETs on their websites, comparison elements are lacking. The companies are, in fact, not revealing a lot of information regarding the specificities of their devices. In particular, the main issue encountered is that most do not disclose any data to the public and the few that do offer specifications that are not comparable.

In this context, Finabel suggests to whom has access to this information to conduct more research on the topic and make it public, as the civilian side could greatly benefit from it. In addition, companies that operate in the sector should be more open about the specifications of their device to allow the users to compare and decide which product suits their needs better. While understanding that sharing detailed information on the manufacturing process would benefit mostly the competitors, it must be understood that sharing information about the characteristics of a product brings benefits such as publicity to the company and showing transparency, which the buyers appreciate.

Regardless of these notes, some conclusions can be drawn. The implementation of MANETs in military communication systems presents several challenges. As noted above, most of them come from their wireless and self-arranging nature. Among them, it should be reminded that they are less reliable than other types of telecommunications, the signals are more easily lost, the flaws are more challenging to be identified, and finally, the energy utilisation of the devices is higher because of the constant rerouting of the communication channel as well as the reorganisation of the nodes.

All things considered, MANETs are still worth their utilisation because of their benefits. The list of benefits in the section dedicated to the advantages of MANETs can be summarised as one great convenience. Even if not used as a primary communications tool, they offer a last resort when centralised telecommunication channels are damaged or disrupted. This is extremely useful in emergencies in the civil and military world.

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