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Race between Mobile Network Infrastructure and Smart Device Capabilities: Readiness and Implications

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ABSTRACT
This study examines mobile communication network infrastructure and device development, assessing progress and failures. Smartphones featuring biometric verification, high-definition cameras, and voice-activated assistants have increased mobile Internet use. Smartphones use Wi-Fi and 3G, 4G, and 5G cellular networks to make communication faster and more reliable, revolutionizing it. However, data-intensive devices are increasing network traffic, straining existing infrastructure. Modern technology like millimeter-wave frequencies is needed to boost mobile communication networks, especially 4G networks, to satisfy this growing demand. This study found that mobile communication infrastructure drastically underserves traffic control and emergency communication. These functionalities are becoming increasingly important as mobile devices proliferate. The report underlines the need to address these concerns and investigates innovative technology that improves traffic management and emergency communication systems to bridge the gap between present infrastructure capacity and mobile device usage.

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Introduction
Mobile devices have completely transformed the way we use the Internet by allowing us to access information and communicate with others whenever and wherever we like. Mobile Internet connectivity has become essential to our daily lives as a result of the meteoric rise of mobile devices. Cellular technology, most often known as "cell phones," is the foundation of mobile phone networks.

Cellular technology uses a network of interconnected tiny transmitters rather than a single large transmitter. Cellular networks support high-speed data and voice communication, allowing cellular devices with strong multimedia capabilities and seamless roaming functionality to operate [1]. In the last several decades, cellular networks have expanded to become the backbone of the telecom industry.

Early Internet-connected handheld devices were enumerated by as personal digital assistants (PDAs) from the 1990s. Portable personal digital assistants (PDAs) are characterized by their capacity to store and retrieve data, as well as their ability to connect to the internet through Wi-Fi. Modern, handheld gadgets that double as cell phones and digital assistants are known as smartphones. According to, two of the first smartphones that were released in the late 90s and early 2000s were the Ericsson R380 and the Nokia 9000 Communicator [2,3].

Smartphones nowadays, such as the iPhone and Android, come equipped with features that were previously unavailable, such as high-resolution cameras, voice-activated assistants, and biometric authentication. Worldwide, 6.56 billion individuals accessed mobile Internet in 2021, with smartphones being the primary means of access. Mobile devices can connect to the Internet using wireless transmission. 3G, 4G, and 5G cellular networks and Wi-Fi have greatly improved the speed and reliability of online connections. Internet access on the road is now a possibility for travelers. With the advent of applications, mobile internet access and usage have been greatly improved. A plethora of social media platforms, e-commerce sites, and mobile banking services are at the fingertips of smartphone owners [4].

The proliferation and reliance on data-hungry gadgets, such smartphones and laptops, has caused traffic to skyrocket. GMDT increased by 74% in 2015, hitting 3.7 exabytes/month. Experts predict that by 2020, this figure will have tripled to 30.6 exabytes. Fourth-generation (4G) networks were unable to manage the influx. So, future wireless standards will have to employ millimeter wave (mm-wave) carrier frequencies between 3 and 300 GHz to boost bandwidth. The accessible microwave spectrum is dwindling as cellular communication technologies continue to operate below 3 GHz. With so much unused spectrum, especially between 20 and 90 GHz, the transition to millimeter-wave frequencies is imminent [5].

Under this critical demand and supply differences, this article is planned and composed as an analysis to assess the current mobile communication infrastructural capacity and communication demands of mobile devices. The study aims to make the abovementioned evaluation and attempts to justify the identified shortage in mobile communication's infrastructural capacity to satisfactorily fit up with the mobile devices. In this article, we have emphasized on two main infrastructural shortfalls as identified in mobile networking models: Traffic management and emergency mobile communication need.

We've explored and analysed these two cases and justified their importance. Also, we provided a number of evolving technologies that support these two requirements.

Related Work

In the work of, the scholar examined on the area where mobile communication interconnection technology is at the moment and where experts think it's headed. In order to delve into the characteristics and primary uses of modern mobile Internet communication technology, this study makes heavy use of theoretical research conducted at the technical and demand levels. In addition, the research has extensively predicted the future development of mobile communication interconnect technology, based on the present results [6]. This research confirms previous predictions about the proliferation of IoT devices and the impending arrival of 6G networks.

in his work demonstrated the primary library and information services offered through the utilization of mobile technology in order to meet the information requirements of diverse users. The research examines significant mobile gadgets utilized in library and information services [7]. The paper provides an overview of library and information services on mobile devices. The objective is to identify crucial aspects that impact the application of mobile technology.

The researchers stressed that mobile technology will revolutionize the existing means of information transmission and seamlessly integrate ICT as a vital component in our daily life. This research suggested that academic libraries may utilize mobile technology as effective instruments to attract reluctant customers to the library, mostly due to their convenience. It also proposed specific strategies to achieve this goal. The research stated that mobile technologies and applications have become a blessing to libraries.

According to, a wide variety of businesses have seen a dramatic uptick in the use of mobile communications devices as a result of the latest innovations in IT convergence technologies. Several projects based on mobile communications have been initiated as a result of this, including u-traffic, u-health, u-ports, and u-cities. The need for one-on-one assistance is on the rise as a result of technological developments like convergence and an aging population. Competition among mobile communications institutions has heated up as a result, and the industry is now more focused on serving individual consumers [3].

When providing ubiquitous services, the emphasis has shifted to satisfying customer expectations and desires. The use of mobile communications technology is thus increasing in convergence-related sectors. Mobile communications systems face a plethora of research challenges in convergence scenarios. Processing overhead is one of the elements that can impact service settings. Therefore, cutting-edge approaches, models, computational techniques, and domain expertise in multimedia applications and business services must be considered.

The work of [8], the primary concern for mobile communication providers is effectively managing the anticipated increase in traffic resulting from this worldwide trend. The standardization of Long Term Evolution (LTE) by 3GPP facilitated the provision of enhanced broadband services and improved traffic management. NTT DOCOMO introduced "Xi" (crossy) LTE in Japan in December 2010. The service has significantly expanded since then. LTE enhances the efficiency of the radio spectrum and increases the speed at which consumer data is transmitted. When comparing the maximum download speed of 14 Mbps for 3G (W-CDMA/HSDPA) to LTE, LTE has a significantly higher maximum download speed of 300 Mbps.

In addition, 3GPP is in the process of standardizing LTE-Advanced (LTE-A), a technology that would significantly enhance the performance of LTE. The implementation of LTE-A improves the speed at which data is transmitted in the downlink direction and optimizes the utilization of available spectrum in this location. This presentation provides an overview of the development and evolution of mobile broadband and smartphones. The article covers the LTE-A standard and the current trial findings of NTT DOCOMO's prototype. The work also discusses the requirements and approaches for antenna and propagation research in order to develop LTE-A systems and technology.

In order to meet the rising demand, [9] stresses that wireless networks must be expanded. Accordingly, this study measures and analyzes the economic and technological challenges that come with this process. Allocating more radio spectrum, improving spectrum utilization across regions, and increasing data transmission capacity per MHz of spectrum in a specific region are the three primary approaches to capacity growth. In order to increase the capability of mobile wireless networks, the article describes numerous basic methods. It then goes on to evaluate how each of these approaches affected the capacity growth of US networks throughout time.

The paper describes the features of 4G LTE wireless technology and how it has evolved to improve network capacity. Quantifying and comparing the capacity expansion potential of LTE-Advanced and classic spectrum reuse with forecasts of future demand allows us to analyze the capabilities of U.S. networks to satisfy demand. According to the model provided, the expansion of wireless capacity in the US will fall short of meeting the expected growth in demand unless spectrum licenses are expanded by 560 MHz from 2014 to 2022. Claims that there is no spectrum scarcity in the US are disproven by this finding.

identified that cellular service providers also prioritize enhancements in performance. According to them, this is particularly accurate in the domain of receiving and relaying emergency crash notification signals dispatched by automotive telematics systems. The research presents a unified model that integrates the base station location, frequency channel assignment, and emergency notification concerns using a mixed integer-programming (MIP) approach. The objective of integrating these three concerns into a unified model is to tackle the interconnectedness among them in order to enhance the design of the cellular system [10].

The recommended formulation attributes have enhanced our comprehension of the problem structure. In this work, an instance generator is developed that creates test cases in a random manner. To achieve prompt and exceptional solutions, it is recommended to employ a few greedy heuristics, which might be very effective in certain scenarios. The authors developed a Lagrangean heuristic approach that builds upon the answer obtained by the greedy heuristics to further minimize the difference from the ideal solution. Finally, a case study example is presented and the effectiveness of the methodologies is assessed by thorough numerical testing.

stressed on the idea of mobility management in next-gen wireless networks and accordingly thoroughly investigated the subject. Many existing approaches have been introduced to address the identified problems of location registration and handoff management. There is an emphasis on creating solutions that can be utilized in varied networks because of the expected increase in worldwide roaming. Media Independent Handover Services, a component of the IEEE 802.21 standard, were also discussed in the presentation as a way to ease handoffs. The authentication and security issues with next-gen heterogeneous networks are quickly covered in the book. The work concludes by highlighting several open research questions in mobility management [11].

This article of provides an examination on the potential of mobile communication in people's daily lives. It then utilizes the Mobile Broadband (MBB) service and the Internet of Things (IoT) to forecast traffic patterns and requirements for the next ten years. The designated performance metrics are employed to ascertain the specific requirements arising from typical usage scenarios following an analysis of both the service's demands and the users' wants. In order to achieve our objective of providing affordable 5G service, we also consider the requirements of network deployment and operation [12].

Finally, the capabilities and efficiency requirements of the 5G system are exemplified by a flower. To realize the 5G vision of "information at your fingertips, everything within reach," the technology will provide a data rate equivalent to fiber, a user experience with minimal latency, the capability to connect over 100 billion devices, and a consistent performance in all scenarios. Additionally, it will significantly enhance energy and cost efficiency by more than a hundredfold.

contended that more resilient technologies that can perform well in harsh conditions can be created or selected with the help of research on how communications systems behave in hostile environments [13]. This article evaluates the present state of the art, the main causes of failure, and the weaknesses of communication systems during catastrophic events. At the outset, we stress how crucial communication systems are. After that, we take a look at the literature that's pertinent, investigate possible communication breakdowns, and assess how such breakdowns affect human life in general and emergency response scenarios in particular.

The use of communications throughout various stages of extreme events is also investigated and studied. Based on multiple case studies, we identify the main weaknesses and limitations that communications systems might face. Overall, the work examined on what makes communication systems work in challenging environments and what has to be in place for them to avoid or at least cope well with communication breakdowns.

worked on 5G mobile communication technologies and examined if the infrastructure can meet the requirement for wide and uninterrupted spectrum by 2020 in the high-frequency band, which is the frequency range between 6 GHz and 100 GHz [14]. Various corporate and academic groups have worked together to allocate and utilize frequency resources between 6 GHz and 100 GHz for 5G and future wireless communication networks.

This paper details the current status of field testing covering the frequency range of 6 GHz to 100 GHz, as well as the allocation of possible 5G frequency bands. Given the importance of understanding the channel's inherent characteristics and making use of its high-frequency range for 5G and future wireless communication systems, we review the recent progress and challenges in this area of research. This covers issues with channel parameter studies and the platforms utilized for such studies.

Introduced a novel concept known as the Traffic-Aware Multi-Tier Flying Network (TMFN). The physical structure of a TMFN can be modified at any moment to accommodate the evolving requirements of the network's users, who are identified based on their geographical locations and the specific sorts of data they receive. The network consists of Flying Mesh Access Points (FMAPs) and Gateways. The concept is implemented by providing a novel algorithm named NetPlan, which aims to enhance the overall data transmission capacity of the TMFN without compromising its coverage. The system utilizes user traffic needs to dynamically calculate the coordinates of the FMAPs (Fixed Mobile Access Points) and the coverage areas of Wi-Fi cells. By validating the proposed NetPlan method, simulated results obtained in typical TCE scenarios demonstrate improved Quality of Service measures, particularly in terms of mean throughput [15].

Pointed that the main factors determining the effectiveness of wireless communication are the available bandwidth and the signal power [16]. Nevertheless, the limited availability of these resources imposes restrictions on the maximum number of devices that may be supported by the wireless system. The main elements that contribute to the limitations are government rules regarding transmission bandwidth and the utilization of low-powered devices in wireless systems.

Operators are seeking methods to enhance channel capacity in response to the limited availability of wireless resources. Nevertheless, each chosen methodology or method comes with its own distinct challenges. This study investigates the factors that limit the ability of wireless channels. This paper explores various approaches developed to enhance the capacity of wireless systems and assesses the limitations associated with each of these methodologies.

Cellular networks, as discussed will adopt a diverse multi-layer structure that includes device-to-device networks, macro-cells, and several types of small cells to assist users in attaining their desired quality-of-service (QoS). The multi-layer method significantly influences many research endeavors that focus on interference management and resource allocation in 5G networks [17]. The growing need for cellular service and the scarcity of resources to support this need have presented a problem in properly overseeing network traffic and operations, necessitating efficient deployment of resources. One of the key challenges is to reduce network congestion in order to enhance the Quality of Service (QoS).

Although several review papers have been published on resource distribution, none of them have specifically addressed the allocation of resources in the context of 5G. This study aims to analyze the issue of resource allocation in the context of 5G technology. It categorizes various resource allocation methodologies published in the literature and assesses their usefulness in enhancing service quality. This survey specifically examines the methods used to evaluate network performance. The purpose of the review is to offer academics clear directions for future research in resource allocation strategies in 5G, by thoroughly analyzing the existing information.

From the literature review, we get that there have been significant advancements in mobile communication technology, yet many areas of study still lack enough investigation. Despite their focus on the current state and applications of mobile communication existing challenges on battery life and bandwidth limitations are less focused on. While converging the IT and mobile communications there is no significant researches that handle the emergency coverage into account specifically. The incorporation of new technology like 6G is less analysed and validated so far, instead focusing on the proliferation of LTE and wireless networks. Nonetheless, researchers have acknowledged the 5G networks have performance and resilience issues, yet none offered thorough solutions for optimizing the allocation of resources. Multiple researches have examined ways to manage mobility, the capabilities of 5G networks, and innovative network ideas. But they didn't look at the limits caused by power and bandwidth regulations very closely. To fill these gaps, this study examines how future mobile networks will handle bandwidth, power constraints, and resource distribution.

Study Problem and Motivation

The primary aim of this study is to examine the methods of standardization and overcome the limitation of bandwidth shortages. These two aspects as observed in the existing researches are expected to enhance the efficiency and expandability of mobile networks. To improve the quality-of-service of 5G and 6G networks, it is necessary to explore methods for increasing channel capacity, examine current and emerging resource allocation systems, and consider the integration of new technologies to overcome these limitations. The study thus attempts to investigate the precise prerequisites for emergency coverage and offer suggestions for enhancing network resilience.

Methods and Tools

The research, keeping in view the existing major lacking areas as mentioned in the above section is designed in the form of deductive research done by means of exploratory and analytical approach. The study intends to relate the demand and need of improvement of mobile communication infrastructure in terms of channel allocation and traffic control. At the same time, the research explores, identifies, evaluates the extent of mobile communication capacity in conditions of any kind of disruptions and natural hazard where emergency communication is essential and are of prime need.

To establish the study objectives as mentioned above, the research has gathered both factual and statistical facts and used them to analyse and evaluate the current scenario of mobile communication. Facts are collected by specifically focusing on the exploration areas and are analysed accordingly. Qualitative analysis is done supported relevant data interpretation as and wherever required by using conceptual methods.

The present study ultimately agrees with the recommendation of technological wideness to incorporate diverse user demands and capacity of handling conditions of emergency, like natural hazards, mass communication failure, disruptions of access, etc.

Findings and Discussion

Growth of Mobile Communication, Usage and Demand from Mobile Users

In this analysis, we begin by discussing on the trends and patterns that the mobile technology followed alongside presenting the development of mobile communication network and its features aimed to meet the consumer demands. We take the resources from the survey article of and present the said scenario [17].

The table below shows the phases of development in mobile networking along with the cellular technologies that are meant to serve the user demand of networking activities.

Generation	Time Period	Key Technologies	Switching Method	Data Rate	Main Features and Improvements	Spectrum
1G	Early 1980s	TACS, AMPS, NMT	Circuit Switching	2.4 kbps	Analog signals, poor capacity, no security, inferior voice quality, susceptible to eavesdropping	Licensed
2G	1990s	GSM, CDMA, IS-95	Circuit Switching	64 kbps	Digital signals, improved battery life, email, SMS, better voice quality, limited data services	Licensed
2.5G	Late 1990s	GPRS, EDGE, CDMA2000	Circuit and Packet Switching	144 kbps	Enhanced data rate, multimedia messaging, internet access, combination of 2G infrastructure with new packet-switching techniques	Licensed

3G	Early 2000s	UMTS, W-CDMA, EVDO, HSDPA/ HSUPA, CDMA2000	Packet Switching	2 Mbps	High data rates, IP-based services, improved QoS, global roaming, video calling, higher energy consumption, expensive infrastructure	Licensed
3.5G	Mid 2000s	HSDPA, HSUPA, LTE, WiMAX	Packet Switching	5-30 Mbps	Enhanced data rates, peer-to-peer file sharing, on-demand video, improved coverage and quality, increased system capacity	Licensed
4G	Late 2000s	LTE-Advanced, WiMAX	Packet Switching	100 Mbps - 1 Gbps	All-IP network, high-definition video streaming, video chat, digital broadcasting, mobile TV, multimedia messaging, seamless integration of services, high bandwidth	Licensed
5G	2020s	BDMA, FBMC, massive MIMO, small cells, beamforming	Packet Switching	1-10 Gbps	Extremely high data rates, ultra-reliable low latency communication, massive IoT connectivity, autonomous driving, smart health, enhanced mobile broadband, Industry 4.0 applications, improved spectral efficiency	Licensed and Unlicensed
6G	2030s (anticipated)	Terahertz communication, AI integration, advanced antenna technologies	Packet Switching	Up to 1 Tbps	Ultra-high-speed internet, intelligent connectivity, pervasive AI, quantum communication, ubiquitous connectivity, extremely low latency, enhanced security, massive machine-type communication	Licensed and Unlicensed

The graph shows the growth trend of mobile networking technology:

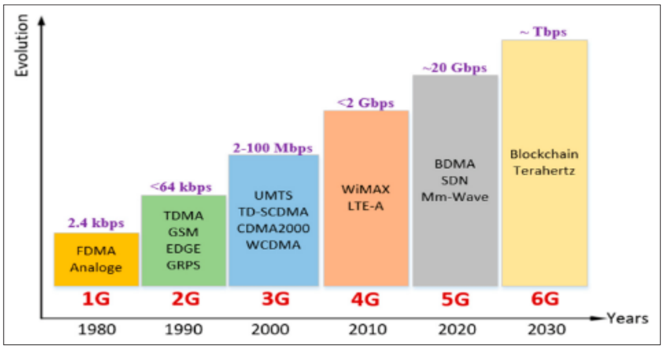

Figure 1: Graph showing the growth of Mobile Networking Technologies [17]

Infrastructural Flaws in Mobile Network

Core Mobile Networking Architecture

The development trend in the above table needs elaboration to understand user needs, networking methodologies, 4G technology, and future improvements. See that mobile network architecture has improved but still has issues. To accommodate consumer demand for fast internet, the access network has improved data transfer speeds and latency. However, fundamental network construction has been slow and piecemeal.

The requirement to support outmoded technologies like 2G and 2.5G has resulted in a complex system topology with several core networks from different generations. The infrastructure's limited databases, servers, and gateways that serve all User Equipment (UE) haven't changed much. The signaling and data planes of LTE have been separated, yet the architecture has stayed the same for 30 years.

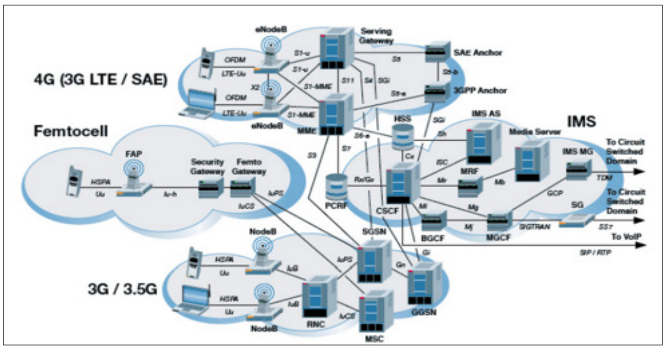

Figure 2: Traditional Cellular Network Architecture [18].

4G technology has advanced, yet its structure is vulnerable. Scaling and managing the growing data flow are tough due to the monolithic core network. Integrating multiple generations of technology into a basic design increases complexity and operating issues. Reliance on a few centralized databases and gateways can cause bottlenecks and system breakdowns, reducing network dependability and efficiency. 4G networks use more energy than previous iterations, requiring more effective and ecologically friendly techniques.

New technologies like SDN and NFV propose a change from hardware-centric to software-centric systems [18]. This technique uses Virtual Machines to conduct important network activities on generic hardware, improving flexibility and cost-effectiveness. It simply copies the existing software structure without actually changing the approach. The Virtual Core Network (VCN) design proposes a deeper evaluation.

Each User Equipment (UE) has a unique virtual instance of the Enhanced Packet Core (EPC), creating a peer-to-peer network with Virtual Machines. This customizable and widely distributed framework can stop cellular botnets, create UE-specific security measures, and enable core networks on public or private clouds [18].

Optimised IP-layer and live migration reduce latency and delay in the VCN design. It also weakens backward compatibility, enabling better eNodeBs and new services. The new architecture has advantages, but it requires extensive cellular traffic assessments to optimize its settings. In general, incremental changes to traditional architecture have not addressed network complexity. VCN makes mobile networks more adaptable, secure, and efficient. Due to 4G's limits and the need to support 5G and future applications and services like IoT, autonomous driving, and smart cities, the network needs to be improved. These apps need lower latency, more reliability, and more scalability.

Emergency Mobile Networking

The components of any network, whether it a distributed sensor network or a macro cellular network, will not be able to give their utmost outcome following a natural disaster. According to the Federal Communications Commission, 85 percent of cell towers in neighboring counties were offline after Hurricane Harvey hit the United States recently. Nearly 6,000 base stations were destroyed in 2011 by a tsunami caused by a 9.0 magnitude earthquake on the eastern coast of Japan [19].

Separating the broadband network from an emergency-only wireless network is the greatest long-term solution. There may be certain hardware and frequency range requirements for this wireless network solution. Energy efficiency is crucial for such network systems in light of the post-disaster power shortage. Building a network infrastructure in a catastrophe zone is challenging due to the high implementation costs, energy requirements, and time required. Create dependable, cost-effective, and globally operable public safety wireless communication standards modeled by commercial communications standards. There will be changes to the wireless infrastructure following a terrorist attack, earthquake, or typhoon. While a generic solution may be necessary to ensure compatibility between user devices and post-disaster communication networks, it is by no means guaranteed.

Evolving Technologies and Attention Areas

To emphasize on the need of enhancement of network communication in disaster condition, we present a 2018 case study given below:

Recent volcanic eruptions in Vanuatu have forced hundreds of people to flee Ambae [20]. The disaster management operators cooperated with Digicel, a local mobile network operator, to study mobile network data using pseudonyms for the government and humanitarian organizations.

Humanitarian relief during and after natural disasters requires accurate and updated information about affected communities and individuals, especially displaced populations. Numerous studies in the past decade have shown that mobile network data can improve public policy and humanitarian operations, but this technology has not yet reached its full operational potential.

The tracking model followed the GSM Association's privacy requirements when studying mobile network data in Vanuatu. This research prioritizes privacy and data security, and we use risk assessment techniques to monitor new digital data sets in our Global Pulse network [20].

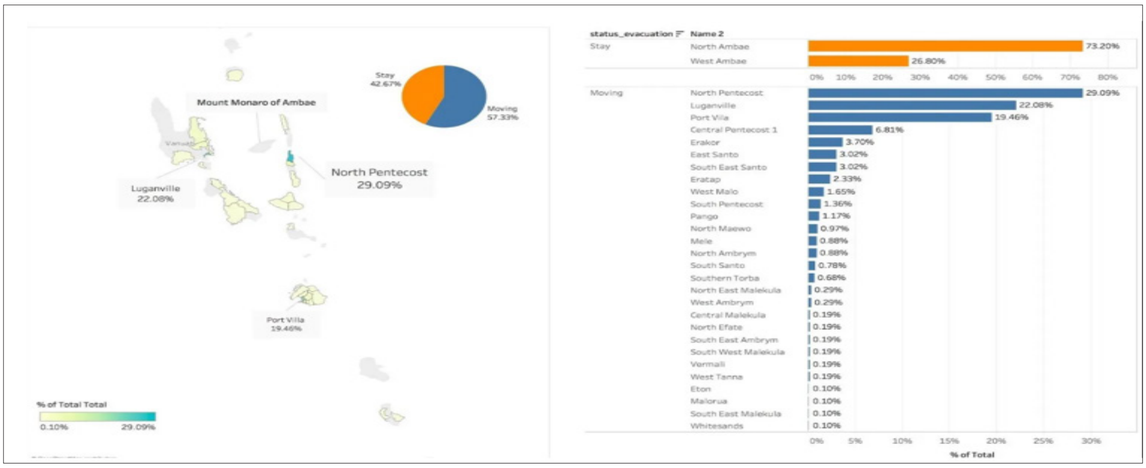

Figure 3: Tracking Outcome of Ambae Residents in 2018 Natural Disaster [20].

All mobile network operator-controlled systems must be analyzed, and GSMA laws require pseudonymization of subscriber data. The local data science team developed humanitarian intervention statistics from pseudonymized mobile network data like national statistics from census data. Starting with cell tower network signals, we used wavelet and multifractal analysis. The data collection demonstrated regular patterns, proving its usefulness for real-time outlier detection. According to official accounts, all Ambae inhabitants were forced out. However, cell network data showed that few individuals remained on the island throughout eruptions and crises. This proves public emergency response worked.

Coming to evolution of technology till date, we present the evolution, features and shortfalls of the existing mobile networking approaches so far [21]:

Approach	Features	Shortfalls
Land Deployable Radio Units (LDRUs)	- Quick setup for localized communication	- Limited coverage area
	- Portable and easy to transport	- Dependent on availability of power supply
	- Suitable for short-range communication	- Not suitable for large-scale disasters
Satellite Communication	- Wide-area coverage	- High cost
	- Reliable in remote areas	- Requires basic operational knowledge
	- Unaffected by terrestrial disasters	- Limited to few first responders and survivors
Connectivity on the Go	- Utilizes existing infrastructure and technology	- Can be expensive due to technology integration
	- Supports backup transmission	- Dependent on the availability of existing infrastructure
	- Flexible deployment for various scenarios	
Ad Hoc Networks (VANETs, MANETs)	- Self-organizing, dynamic networks	- May have connectivity issues in highly dynamic environments
	- Effective for localized disaster response	- Vulnerable to security threats
	- Low setup time	- Limited range and scalability
Wireless Sensor Networks (WSN)	- Efficient for monitoring and data collection	- Susceptible to environmental interferences
	- Delay-tolerant networks	- Requires careful planning for sensor deployment
Wireless Mesh Networks (WMNs)	- Robust and self-healing networks	- Can be complex to configure and manage
	- Provides extensive coverage	- Performance can degrade with increased number of nodes
Professional/Private Mobile Radio (PMR)	- Secure and reliable communication	- High cost for setup and maintenance
	- Dedicated frequencies for emergency services	- Limited interoperability with other communication systems
Unmanned Aerial Vehicles (UAVs)	- Enhanced aerial view and coverage	- Dependent on battery life and weather conditions
	- Flexible and mobile deployment	- Requires specialized training for operation
	- Supports mobility and navigation models for dynamic environments	- Regulatory and privacy concerns

Given below are the traditional mobile networking technologies operational in emergency conditions:

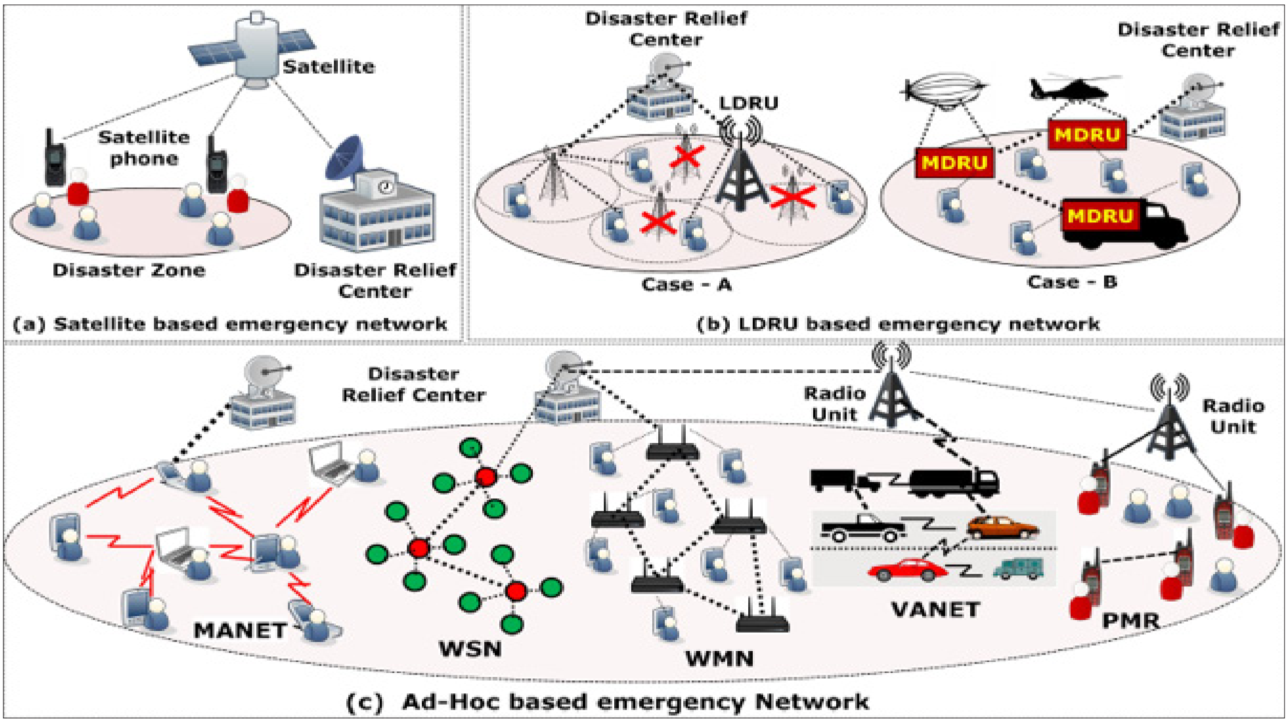

Figure 4: Emergency Mobile Communication Networking Operational Approaches [21]

Mobile Communication Traffic Control

In response to these difficulties, a set of tools known as Network Traffic Monitoring and Analysis (NTMA) were developed to track how well networks were functioning. Predicting the future of network load and its behavior is the primary subject of Network Traffic Prediction (NTP), a notable branch of NTMA.

The goal of network traffic prediction and analysis (NTP) is to improve network performance by analyzing and predicting network traffic. Numerous networking issues, such as resource discovery, congestion control, analysis of network activity, and provisioning of resources, are addressed in this project by use of NTP. Numerous schools of thinking exist with respect to NTP, with statistical and ML being the two most prominent.

The table given below shows the statistical and ML based network prediction and analysis tools that are used to track the communication network demand and allocate the channels [4].

Category	Model/Technique	Description
Statistical Approaches	Autoregression Moving Average (ARMA)	Combines autoregressive (AR) and moving average (MA) models; assumes stationarity in time series.
	AutoRegressive Integrated Moving Average (ARIMA)	Extends ARMA by integrating differencing to ensure stationarity; denoted as ARIMA(p,d,q).
	Seasonal ARIMA (SARIMA)	Incorporates seasonality into ARIMA models, accounting for seasonal patterns in data.
	Fractional ARIMA (FARIMA)	Extends ARIMA to support fractional differencing, accommodating long-term dependencies in data.
	Generalized Autoregressive Conditional Heteroskedasticity (GARCH)	Models time-varying volatility by extending the ARCH model, focusing on conditional variance.
	Fuzzy-ARIMA	Fuzzifies ARIMA parameters using fuzzy regression for improved flexibility in prediction.
ML Approaches	Artificial Neural Networks (ANNs)	Universal function approximators capable of learning complex nonlinear dependencies; consist of input, hidden, and output layers.
	Deep Neural Networks (DNN)	ANNs with two or more hidden layers; handle complex patterns and relationships in data.

	Recurrent Neural Networks (RNN)	Handle sequential data by recycling inputs in hidden layers; suitable for time-series prediction.
	Long Short-Term Memory (LSTM)	An RNN variant addressing long-term dependency issues through a triple gate mechanism and feedback loops.
	Reinforcement Learning (RL)	Utilizes agents that learn optimal actions based on the consequences of their actions in Markovian environments; Q-Learning and Deep Reinforcement Learning (DRL) are notable algorithms.
	Deep Reinforcement Learning (DRL)	Combines Q-Learning with DNN to enhance learning performance in dynamic environments; interacts with networks to predict future behavior.
	Semi-Supervised Learning (SSL)	Combines small amounts of labeled data with large amounts of unlabeled data; uses techniques like Active Learning to improve model accuracy.
	Supervised Learning (SL)	Trains models using historical labeled data to predict outcomes; commonly used in classification and regression tasks.
	Clustering	Unsupervised learning technique grouping similar data points; can identify patterns in network traffic.
	Rule Extraction	Derives actionable rules from data using various ML techniques; aids in understanding underlying patterns in network traffic.

Let us discuss on the need of enhancement of the network traffic prediction system. With the proliferation of IoT devices, 5G networks, software-defined networking, network functions virtualization, and fog computing, robust NTMA solutions are essential. By using traffic forecasting, classification, anomaly detection, and fault detection to issues with network management, solutions based on Big Data Analytics enhance accounting, performance, fault, configuration, and security [4]. Upholding quality of experience and network-oriented quality of service requires real-time network sensing and trend monitoring.

We think about loss rate, jitter, delay, and throughput. Due to its minimal computational and privacy costs, Shallow Packet Inspection (SPI) is utilized for real-time data extraction. On the other hand, Deep Packet Inspection (DPI) gathers information about traffic.

Applications for NTP's network traffic prediction include detecting security threats, defects, and quality of service. Time Series Forecasting (TSF) has been the gold standard for traffic volume forecast due to its reliance on past data dependencies, simplicity, and low computer complexity. Because of the diversity, speed, and complexity of networks, non-TSF methods have been more popular. Using packet headers and flows, these algorithms can forecast network flows. The primary approaches to NTP involve statistical analysis and ML.

Machine learning algorithms, such as ANNs and RL, are better at making accurate and versatile predictions, whereas statistical methods, such as ARIMA and ARMA, examine patterns to foretell future data points. Finally, NTP is critical for mobile network administration since it guarantees top-notch speed, safety, and user happiness regardless of how fast network needs change.

Conclusion and Future Possibilities

In the conclusion of this work, let us mention that the advancements in network communication technologies are required for emergency management and mobile network traffic monitoring after 4G and beyond 2021. There is a growing need for dependable NTMA solutions due to the increasing network traffic caused by developments such as network functions virtualization (NFV), fog computing, software-defined networking (SDN), the Internet of Things (IoT), and 5G networks.

To solve problems with resource discovery, congestion control, and resource provisioning that arise in network management, these technologies employ Traffic Classification, Anomaly Detection, Fault Detection, and Traffic Prediction. Among other statistical methods, Neural Traffic Prediction (NTP) in Network Topology Mapping (NTMA) predicts network traffic and load. By allowing for real-time decision-making and resource allocation, these predictive models enhance network performance and quality of service/quality of experience.

Improved and up-to-date forecasts are made possible by NTMA's expertise in Big Data Analytics. In the age of more diversified and high-speed networks, this technical advancement is crucial to maintaining stable networks and happy customers. The need for accurate, up-to-date information in humanitarian and disaster response was highlighted by the 2018 volcanic eruptions in Vanuatu. Modern network management relies on NTMA due to its state-of-the-art traffic monitoring and analysis technology.

To stay up with the ever-changing conditions of mobile networks, NTMA creates new technologies to make them faster, more reliable, and more equipped for both routine operations and catastrophic calamities. Constant innovation is required to safeguard users and guarantee the reliability of networks in this era of unparalleled connectivity and technological progress.

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