Mobile Networks and Internet of Things: contributions to smart human mobility

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Abstract. Nowadays, our society can be considered as a "connected society" thanks to a heterogeneous network and the growth of mobile technologies. This growth has meant new devices are now supporting Internet of Things (IoT) architecture. Consequently, a new look at the current design of wireless communication systems is needed. Smart mobility concerns the massive movement of people and requires a complex infra-structure that produces a lot of data, creating new interesting challenges in terms of network management and data processing. In this paper, we address classic generations of mobile technology until the latest 5G implementation and its alternatives. This analysis is contextualized for the problem of smart mobility services and people-centric services for the internet of things that have a wide range of application scenarios within smart cities.

Keywords: Mobile Generation Technology, Internet of Things, Networked Society, Smart Human Mobility

1 Introduction

The rise of the digital world has placed technology at the heart of how our society is run, from working to banking to human mobility. The digital age is not just about creating new trends in technology, it is also about impacting society positively. Following on from technology trends based on the digitalization of society, the vital step is the fusion of the digital and physical worlds into cyber-physical environments, namely, an ecosystem of smart applications and services based on the interconnectivity of heterogeneous sensors. In other words, the digital transformation of society has been accelerated with the contributions of new network technologies and the Internet of Things (IoT).

In the last decades, the IoT has seen an increase in density because its real value comes from analyzing the information provided by available sensors. Information fusion improves information completeness/quality and, hence, enhances estimation about the state of things. This trust in activities of the information fusion process and hence IoT smart applications has lead to an increase in the number of connected users. Therefore, there is a need for simultaneous connection with a spectral efficiency, great data rate, security and signaling efficiency, and reduced latency to the final users and the deployed sensors. To answer this need a migration to a new wireless communication should be implemented. In other words, the next mobile generation technology such as 5G should address many challenges for better connectivity and applications of mobile users.

The challenges in each technology lead to the creation of a newer one. Therefore, the tremendous growth wireless communications including mobile generation technologies had in the past 50 years is not surprising [1]. Over the years, each one of them has had an impact on "mobile society" and IoT device users. For example, 1G came when salespersons suddenly had a phone in their car so they could call orders while they were traveling. 2G moved phones into people's pockets, and we were able to start sending text messages to each other. 3G phones began working everywhere, not being limited to a certain region. In its turn, 4G offered inter-operability between various networks. And to increase coverage and to suite both consumers, businesses, and authorities 5G came along.

5G Wireless Communication provides interoperability between all networks and uses packet switching rather than circuit switching. For example, data transfer takes place directly without a pre-connection or no resource reservation because bandwidth is shared among users. Indeed, its flexibility meets different performance requirements of real smart city services such as human mobility. No matter where we are or what we are trying to achieve, the first step to build a human mobility service is to have a robust, reliable, and high speed wireless network. This is the backbone of all potential smart human mobility applications.

In this article, we discuss how important wireless network technologies are to the success of smart human mobility applications. Fortunately, 5G is going to get implemented in various projects but we need further research to understand the potential of connectivity in human mobility services. The aim of this article is to raise awareness to the opportunities generated by the constant evolution of IoT architecture and mobile connectivity. This study intends to survey the level of coverage of IoT architectures in human activity monitoring. Finally, we discuss future directions towards new mobile technologies as an important step to optimize and present new solutions for smart human mobility.

2 A survey on connectivity platforms in IoT

The evolution of Information and Communication Technology (ICT) generates more and more devices which have the ability to communicate with other devices, which is transforming the physical world itself into an information and knowledge system. This digital transformation, although having started in a modest way in the 80's (e.g with analog devices), for increased capacity and intelligence within networks, has led to the development of new IT infrastructure paradigms. For example, in the newest Internet of Things (IoT) architecture whereby capacity, computing, connectivity are moving closer to the devices themselves, closer to the edge of the network, Cloud technologies are becoming important. As a matter of fact, Cisco Systems, Inc. is already a driver of evolution and development in networks that involve Fog Computing, when until recently we only talked about Cloud Computing [10]. However, to better understand where we are in terms of connectivity and computing approaches we need to understand the past and its evolution over time. Table 1 summarizes the properties of each connectivity system and their effects on IoT architectures in the last 40 years.

Table 1. Evolution of Mobile Networks and Internet of Things architectures.

Mobile Networks	*1G*	*2G*	*2.5G*	*3G*	*3.5G*	*4G*	*5G*
Year	1984	1990	1995	2000	2003	2010	2020
Frequency	800 - 900 MHz	850 - 1900 MHz	850 - 1900 MHz	1.6 - 2.5 GHz	1.6 - 2.5 GHz	2 - 8 GHz	$\geq$ 6 GHz
Data Capacity	24 Kbps	56 Kbps	56 - 115 Kbps	2 Mbps	30 Mbps	200 Mbps - 1 GBps	$\geq$ 1 GBps
Services	Mobile telephony	Mobile telephony and SMS	E-mail, Information and Entertainment	E-productivity, E-commerce, ...	Skype, Facebook, YouTube, ...	Identification, Tacking, ...	Monitoring, Metering, ...
Generation Internet	Human to Human	WWW	WWW	Web 2.0	Social Media	Cloud Computing	Machine to Machine
Internet of Things	Network	Internet	Mobile and Internet	Mobile, People and Internet	Mobile, People and Internet	Objects, Devices, Tags and Internet	Data, Ambient Context and Internet

The evolution of Mobile Networks and Internet of Things had 7 phases. Because 0G generation/pre-cellular technology did not support roaming and lead to the to expansion of next generation mobile technology, it all began with 1G technology. This generation had a basic voice analog phone system using circuited technology for the transmission of radio signals. Moreover, it connected two computers together, creating the first network. It used an architecture called Advance Mobile Phone Service (AMPS). This architecture makes a bridge connection between a base transceiver station with a car or mobile, and also links with a mobile telecommunications switching office. This office services to customers from public telecommunications switching networks.

The next generation allowed for the combination of data and voice services such as Short Message Services (SMS), Multimedia Message Services (MMS), Global System For Mobile (GSM), and E-mail with capacity. At this stage, the World Wide Web was invented by connecting a large number of computers, but, although this was innovative, it did not support complex data such as videos. Moreover, it relied on techniques in digital multiple accessing called time division multiple access (TDMA) and code division multiple access (CDMA) standards. In 2.5G, the mobile-Internet emerged by connecting mobile devices to the Internet and also provided support for Wireless Application Protocol (WAP) and Access Multimedia Messaging Services (AMMS), and Mobile games.

To be 3 times better than GSM technology (also called 3GSM) a third generation was created. It is usually referred to as Universal Mobile Telecommunication Standard (UMTS). Beyond UMTS, the 3G was also supported by CDMA2000 technology where, to frame the International standard for 3G cellular networks, the International Telecommunication Union (ITU) signed the International Mobile Telecommunications (IMT) standard in 1999. Thereby, this generation supported 3GPP and 3GPP2 [3]. Its main disadvantage is that it requires higher bandwith, needs more network capacity that does not fail in real time applications. This called for a new connectivity technology and this is where the fourth generation comes in.

4G incorporates major requirements such as Quality of Service (QoS). After people joined the Internet via social networks on the previous connectivity platform, then, inter-operability between various networks, monitoring, tracking, and moving bigger data volume began to be accepted. This is done by small applications such as MMS, Video Chat, HDTV, Digital Video Broadcasting (DVB) and Wireless Mobile Broadcast Access (WMBA). Besides, the OFDM technique divides the channel in narrowband to transmit data pockets with greater efficiency. It is provided by a combination of CDMA and Interim Standard 95 (IS-95) (first CDMA-based digital cellular technology) due volume of data implemented. However, there are some major issues in this mobile network generation including data modification, scrambling attacks, expensive hardware and higher dependency on battery.

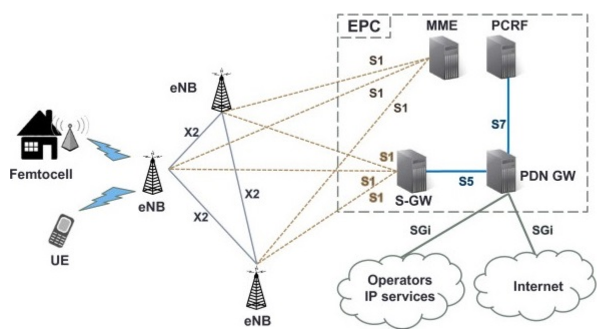

Fig. 1. Architecture of LTE-Advanced network with Evolved Packet Core (EPC), Mobility Management Entity (MME), Public Data Network Gateway (PDN GW), Serving Gateway (S-GW), evolved Node B (eNB), Serving Gateway interface (SGi), Policy and Charging Rules Function (PCRF), and User Equipment (UE) (based on [12]).

Once again, these issues called for a new connectivity platform, and that is 5G. The technology in this new mobile generation is called LTE-Advanced (LTE-A), and it is configured to support, just like 3G, Frequency Division Duplexing (FDD) and Time Division Duplexing (TDD) [8]. The LTE-A architecture is presented in Fig. 1. 5G improves communication coverage, data rate, reduces latency, and creates a true wireless world experience. Although it is not yet totally deployed, IoT is one of the main benefits of the 5G cellular network. This would make the most of the higher speed connectivity to allow for seamless integration of devices on a scale never achieved before. In other sections, we will provide more details about the 5G cellular network, the IoT, and contributions both offer to implement smart human mobility services.

3 Mobile Networks Applications

Evolution from the first generation (1G) to the nascent, fifth generation (5G) networks has been gradual. As mentioned in section 2, every successive mobile generation technology has introduced advances in data throughput capacity, growth interconnectivity between devices, and decreases in latency, and 6G and 7G are no exception. Although formal 6G standards are yet to be set, 6G is expected to be at least faster than current five generation (5G) standards. To truly understand how we got here, it is useful to understand what changes and benefits 6G will bring in supporting smart human mobility services.

3.1 5G Architecture

Thanks to 5G, we are entering a new IoT era, with even more pervasive connectivity, where a very wide variety of appliances will be connected to the web. Besides, different authors have proposed architectures to meet the continuous increase in the density of cells. There is no universal consensus on 5G architecture for IoT, but Fig. 2 presents an overview of the components.

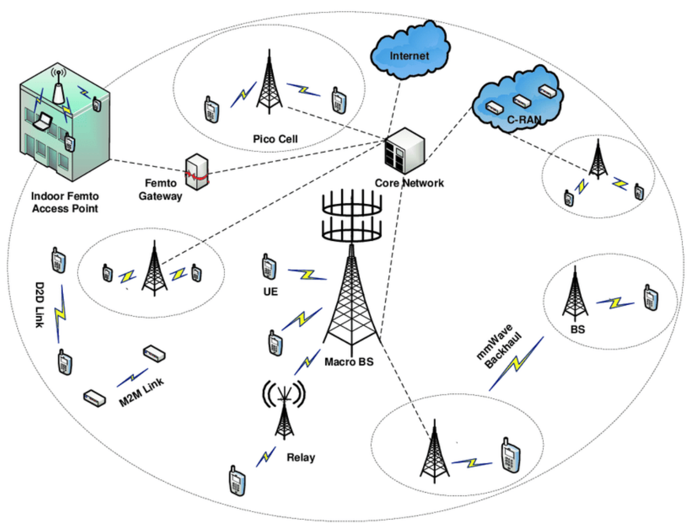

Fig. 2. Architecture of 5G cellular network with Device-to-Device (D2D Link), Base Station (BS), Macro Base Station (Macro BS), Cloud Radio Access Network (C-RAN), User Equipment (UE), and Machine-to-Machine (M2M Link) (based on [7]).

This architecture has been implemented in three levels: transport layer, processing layer, and business layer. For example, in [2], a self-configuring and scalable architecture for a large-scale IoT network was proposed. Moreover, with the integration of a cloud-based IoT platform, also known as cloud computing, data processing is done in a largely centralized fashion by cloud computers. Such a cloud centric architecture keeps the cloud at the center, applications above it, and the network of smart things below it [5]. This information center networking is combined by all wireless transmission protocols spectrum bands and standards under a single network control plane, introducing a high number of small cells as pico-cells and femtocells, as well as Wi-Fi hotspots in order to increase bandwidth per cell and provide throughput for end users. For short-range data transmission, which benefit the 5G-IoT with lower power consumption, and better Quality of Service (QoS) for users and load balancing, this architecture seems like a promising solution to enhance network capabilities by allowing nearby devices to establish direct links between themselves. Part of human mobility tracking is transmitted between devices instead of being transmitted through the base station. The main advantages are flexibility and efficiency, thanks to the use of dynamic small cells instead of fixed cells. Therefore, the 5G architecture should be included in smart city solutions.

3.2 Impact on Cities

5G networks are predicted to carry 45% of global mobile traffic by 2025 - a 10% increase from what was forecasted in June 2019. Basically, 5G will support nearly half of the world's mobile data traffic, but has the potential to cover up to 65% of the world's population [4]. Moreover, we are in the final stage of the next technological revolution: the development of a ubiquitous wireless network that will marry data collection and computation with billions of devices. This will push the number of mobile devices to the extreme, with 10^7 devices per km^2 in dense areas (up from 10^6 in 5G) and more than 125 billion devices worldwide by 2030.

Service providers and consumers have shown enthusiasm in different mobile generations. This reflects they are improving people's lives in many different aspects. Unlike cell phones in 1995, cell phones can do much more than just make a phone call. Nowadays, 5G is definitely taking off, while 6G and 7G will be next, and having a positive impact on the development of new services and solutions for smart cities. If we review the characteristics and foreseen requirements of use cases that represent 5G services, we provide a comprehensive view in many new applications that are already viable today, particularly in urban areas and cities.

Autonomous Vehicles This new application requires a response in fractions of a second, and the use of Ultra Reliable Low Latency Communication (uRLLC). A main goal is a vehicle-to-everything communication network. This enables vehicles to automatically respond to objects and changes around them almost instantaneously. A vehicle must be able to send and receive messages in milliseconds in order to brake or shift directions in response to road signs, hazards and people crossing the street. Sure, autonomous cars may be fitted with cameras capable of face recognition and/or LIDAR scanners that can pick out moving objects in the vicinity of the vehicle. Eventually all devices should alert passing vehicles to the presence of a pedestrian.

Drone Management Drones have a vast and growing set of use cases today beyond the consumer use for filming and photography. For example, utilities are using drones today for equipment inspection. Logistics and retail companies are looking for drone delivery services. The trend is to push the limits of drones that exist today, especially in terms of range and interactivity. With 5G we are able to see beyond current limits with low latency and high resolution video. It also extends the reach of controllers beyond a few kilometers or miles. Moreover, these developments have implications for use cases in search and rescue, border security, or surveillance.

Human Activity Trackers 5G has a very gradual and initially negligible impact on consumer wearables such as smartwatches, mobile phones. Where, for example, the maker of the smartwatch provides secure cloud services and enhanced big data analytics to truly become the personal trainer of the wearer. An ultra-fast connection to massively powerful compute power on the cloud will come in useful for keeping wearables small, light and battery-efficient. 5G-enabled wearables play a major part in 'smart roads' of the future. While the smartwatch or Fitbit may not require high-speed connectivity with ultra-reliable, low-latency communications, it is used to alert autonomous and assisted vehicles to the presence of its wearer close to the road, or crossing the road, a scenario called "vehicle to pedestrian" communications.

Although 5G enables the connection of thousands of wearables and sensors per square kilometre, supporting both the high-speed, high-bandwidth mode and the low-power, long-life, small-messaging model, this use-case won't support much data per device, so it will be hard to apply AI to it. Basically, what this mobile phone generation will do is to provide a permanent connection where wearables could swap between them as and when they need to.

4 Emergent mobile technologies and infrastructures

5G continues to be at the center of the discussion around networking technologies, as well as Internet of Things use cases. Nevertheless, Low Power Wide-Area Networks (LPWANs), Wireless Local Area Networks (WLANs), Bluetooth, NB-IoT to CAT-M1, and LoRa to SigFox, are some of the emergent alternatives able to produce solid applications with their own unique use case scenarios. In fact, an IoT connectivity option that is ideal for one application may be awful for another. No single technology is able to cover all applications. This opens the door for a much broader ecosystem of "best fit" technologies.

4.1 Impact on IoT

For years, the prospect of reaching billions of connected devices is coming from applications that promise yielding revolutionary results. The successful deployment of many of them requires applying transformative enabling technologies and new connectivity models. However, industries such as agriculture, healthcare, activity trackers and smart buildings or homes that may take advantage of short-range technologies such as Wi-Fi, Bluetooth or Radio Frequency Identification (RFID), or long-range communications technology like cellular or satellite, do not need to implement a long-range connectivity solution. Nowadays, there are alternatives with low-power consumption and more advantageous customer engagement models to meet their digital transformation goals.

To this end, LPWANs and WLANs are fundamentally changing the IoT landscape [11]. LPWANs are designed for connecting devices that send and receive small data packets over long distances. Currently, Sigfox and LoRa (beyond NB-IoT, LTE-M, Weightless or InGenu) are the major competitors in the LPWAN space. And while the business models and technologies behind the companies are quite different, the end goals of both Sigfox and the LoRa Alliance are very similar: that mobile network operators adopt their technology for IoT deployments over both city and nationwide low power, wide-area networks (LPWANs), using unlicensed communication technologies. The Sigfox business model takes a top-down approach. The company owns all of its technology, from the backend data and cloud server to the endpoints software. But the differentiator is that SigFox is essentially an open market for the endpoints where manufacturers like STMicroelectronics, Atmel, and Texas Instruments make Sigfox radios. Additionally, only one Sigfox network can be deployed in an area because the company has exclusive arrangements with network operators when they work together. While LoRa or LoRaWAN is differentiated by its open ecosystem, strong security specifications, bi-directional communication, optimization for mobility, and scalability for capacity. The LoRaWAN architecture is a high availability, fault tolerant and redundant platform. It is usually used on fuel tanks, fill level and other valuable data is sent over LoRaWAN networks to tank monitoring solutions used by supply companies [6].

However, LPWANs are not available in many places of the planet, for example, inside a division of a house. Fortunately, there is another alternative to turn to: WLAN (used by Bluetooth 5 and Bluetooth Low Energy, Thread, Wi-Fi, ZigBee or Z-Wave). Although, LPWAN and Wi-Fi 6 use similar technology (e.g, methods for encoding data into radio waves), in building infrastructure, and the way we interact with systems are different. Because they are designed to ensure that people operating from a workstation or in their home can connect on a variety of different devices by using the internet and, consequently, provide different coverage levels. Moreover, in this type of set up, there are no wires connecting the devices to the network,ensuring that they can be distributed across a significant distance. Thus, the major advances coming with 5G and its alternatives will open up ever more opportunities and surprising applications for all of us.

4.2 Impact on asset tracking applications

In a smart city, asset tracking services are expected to overcome different social challenges: be safe, efficient, reliable and provide custom responses. Besides, WLAN and LPWAN networks offer advanced real-time communication services and with a simple density of network nodes, covering indoor and outdoor places where 5G Wireless Communication does not reach efficiently. In this context, these 5G Infrastructure Alternatives are regarded as the ultimate platform to track human mobility in smart buildings or use cases where the frequency/size of messages require low bandwidth.

However, the challenges that exist in the asset tracking space (i.e tracking of human mobility) and indoor positioning include installation, scale and availability. The truth is that it is hard to install a correct amount of hardware required for a given space. The addition of unnecessary hardware leads to redundancy and expenses. On the other hand, not enough hardware can result in dead zones and a failed solution. In addition, as the spaces we wish to use indoor positioning and asset tracking on expands, the complexity, security vulnerability and cost increases as well [9]. What may work well in a small 400 square foot area can cost dramatically different compared to a 16,400 square foot warehouse.

5 Conclusions

According to the evolution and use cases from mobile technologies, we can consider that these technologies resulted from a strong relationship between humans and devices associated to the Internet of Things. As we have seen, the growth of IoT correlates with the direct growth in device users via the Internet. This rapid growth and increase in the interconnectedness between devices and people means there is a wide range of requirements that needs to be met. Thus, the advent of 5G network is expected to massively improve or expand IoT security, increase speed, boost cellular operation with increased bandwidth while also overcoming several network challenges faced in the previous generations of mobile networks.

On the other hand, thanks to the Internet of Things the information we are looking for will help us to know more about our activities at anytime, anywhere and at any place of our life which is only possible thanks to the evolution of connectivity platforms in IoT. For example, it can provide location information from massive device connectivity and improve coverage for everybody. Once people use a set of devices (e.g, smartphones, smartwatches, etc) that take advantage of Global Positioning System (GPS) and Bluetooth Low Energy (BLE) technologies, tracking them is already possible, allowing up-to-date location information.

In its turn, although generations - 2G, 3G, 4G and 5G - have succeeded, different alternatives arise from the design of their infrastructure and their use cases in a internet of things scenario. Using these infrastructure alternatives, for example, we can easily find and locate areas most visited by people or even identify patterns of human mobility in indoor places. But, despite all this, to make all of them available to customers there are costs and challenges. One of the challenges is the cost of rolling out to different proportions of the population and the investment cost for rolling out a high coverage solution, mainly in relation to urban-rural settlement patterns. In addition, there are a wide range of use cases which fall within fast mobile broadband and massive machine communications. All this is built to be available and used to track human mobility.

In the future, we hope to keep the balance between these different network technologies, expanding IoT architectures and enabling the smart composition of smart mobility services that can track user and device actions, with a connection suited to the rquirements of each use case, and the capability to travel between different network endpoints. To this end, we aim to extend frameworks that use multiple connectivity technologies to build services in the context of the internet of things and smart cities.

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