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Abhi Naha and Peter Whale
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1 Beginnings

The mobile phone industry is one which has been characterized by a breathtaking speed of change and development, and anyone who has owned a number of handsets will be aware of the dramatic change evident between a phone of just a few years ago and the latest available models. In order to identify a set of core design issues which hold across generations of handset design, we need to set our sights higher than an analysis of the design of the latest high-end smartphone. We believe a very good place to start is with a review of the relatively short, yet thrilling, history of mobile handsets, providing an opportunity to understand the technological and market issues which have driven this phenomenal development.

1.1 Development of the first mobile handset

1.1.1 A famous telephone call

On April 3, 1973, Marty, a researcher at the US company Motorola, made a phone call from a Manhattan sidewalk to his colleague Joel Engel at the US telephone carrier AT&T.

The purpose of Marty's call that particular Spring day was to inform Joel, that he, Marty, was calling him from the world's first ever portable cellular telephone, beating AT&T in the technology race to develop a viable commercial portable cellular telephone. This first portable cellular phone was unlike anything we know today – consisting of about a kilogram of plastic and electronics, shaped something like a shoe, using analog radio technology, without any form of screen or menu buttons, and yet able to make and receive telephone calls "without wires" and when on the move. Marty, or, to give him his full name,

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Martin Cooper, is now revered by many as the father of the mobile phone.

Ten years and five iterations of the handset design later, the US Federal Communications Commission (FCC) approved for use the world's first commercial portable cell phone on September 21, 1983 in support of the launch of the first commercial cellular network by AT&T in 1983. Weighing in at approximately 800 g, known as the DynaTAC 8000X, and with a ticket price of around $3500, the product was a true technological marvel. Within that first ten-year period from Martin Cooper's Manhattan phone call, the technology had already been miniaturized to approximately half the weight of the original working prototype. The vision which drove Martin Cooper, and a whole host of others, was the radical idea that people would much prefer the freedom to be contacted wherever they happened to be, and to be able to call other people without first needing to know where they were located. It is a reflection of how ubiquitous the mobile phone has become that today this statement seems almost "obvious," yet just 40 years ago this was a remarkable vision of the future of communications. Marty is the first to confess that significant teamwork by many thousands of people has been required to fulfill that vision, and that the vision is constantly being renewed as technological improvements make new capabilities available year by year. In the remainder of this chapter, we take a brief tour through the history of the development of the mobile phone, looking at some of the industry's key moments and reminding ourselves of how rapidly the technology has developed, how this has driven key design issues, and how ubiquitous mobile communications has become.

1.1.2 Early developments in mobile telephony

Before that historic phone call, the early development of mobile phones was characterized by a number of different, somewhat disconnected, inventions and experiments. For example, one Lars Magnus Ericsson (the founder of Ericsson, who retired in 1901 to go into farming) installed a fixed telephone into his "horseless carriage" (car) in 1910. As Lars and his wife Hilda traveled across the country, he would stop his car at various

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places and Hilda would connect two wires from the phone to overhead telephone lines using two long sticks.

Developments in two-way radio communication in the first half of the twentieth century were used in applications such as shore-to-ship communication, for example in 1926 for first class passengers on trains between Berlin and Hamburg, and for military communications during the Second World War. Following the Second World War, military and civilian patrol cars started to use two-way radio communications. In all these early examples, a mobile phone had to stay within a particular area serviced by a specific base station throughout the duration of the telephone call. This meant that mobility was severely limited, as there was no mechanism to transfer the call from one base station to another without first disconnecting the call, and there was no concept of re-using frequencies between different users. Solving these two problems of hand-off or handover between base-station cells, and the ability to re-use frequencies between phone users, were the key innovations which laid the groundwork for the first-generation mobile phones.

Radio telephone services commenced in the USA in 1946, for use primarily in vehicles. These so-called "car phones" were essentially two-way radios which allowed connection via a base station to the landline telephone system. Both the phones and the base stations transmitted at maximum power to ensure the largest possible area of coverage for making and receiving phone calls. The base station allocated two frequencies for the duration of each call – one for receiving and one for transmitting. Although successful, there were obvious limitations with this approach. Because of the high transmit power used, it was not possible to re-use the same frequency between adjacent base stations due to the interference caused. This, coupled with the fact that two frequencies were being used up for each call, meant that the maximum capacity of a base station was reached in a very short time. Nonetheless, the obvious value of being able to make phone calls from vehicles encouraged companies to invest in research and development to work through how to design better solutions which could handle much greater capacity.

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1.1.3 The cellular innovation

In 1947, engineers at Bell Laboratories in the USA had proposed a hexagonal "cell" structure, with base stations transmitting (and receiving) in three directions at the "node" points where three adjacent hexagon shapes coincide.

The essence of the idea was that geographical areas would be divided into small adjacent cells, each operating at a lower power than a single large transmitter covering a much larger geography. Each of the cells would support a number of frequencies, not in immediate use by neighboring cells, which would allow many more two-way radios to be used at the same time. This was a radical idea well ahead of its time, as no technology existed to realize this idea practically for a further 15–20 years. In the 1960s, again out of Bell Labs, the transistor was invented and commercialized, with one of its many applications being to build electronics to realize portable communications with a small base-station cell.

A key advantage of the cellular design approach was to reduce the maximum distance a radio signal had to be transmitted, hence significantly reducing the transmitter power required as well as the amount of interference between adjacent transmitter stations. The ability to use lower-power transmitters also created the opportunity to create portable radio products with their own transportable power supply. Reducing the amount of radio interference also made it possible to utilize the same frequencies across multiple cells that were in the same region, and thus increase the capacity – meaning that more people could use the service at the same time in a particular region.

In 1968, the FCC first proposed to allocate frequencies in the 800–900 MHz range specifically for the deployment of new technologies, in order to solve the key issue of limited call capacity of the existing two-way radio telephone systems.

Research continued, and in 1970 Amos Joel, an engineer at Bell Labs, invented a system of "call handoff" which would allow for a mobile phone to be able to move between base-station cells whilst maintaining a continuous call connection, even if different frequencies were utilized by each of the cells.

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1.1.4 Early commercialization in Scandinavia

It is fair to say that there are many "fathers" of the mobile phone distributed around the world. In Europe, Swedish electrical engineer Östen Mäkital's work in the 1960s led directly to the development of the first-generation NMT system in the Nordic countries, and some would claim Mäkital as the true father of the cellular phone.

In Europe, Ericsson's very first mobile phone was designed in 1956. It weighed 40 kg and was about the size of a suitcase. When mounted in a car, it cost almost as much as the car! Because the entire network for which it was designed could not serve more than about 100 subscribers, it was of limited commercial success.

In Sweden, in 1960, an early car phone system known as Mobile Telephone System A (MTA) was launched, with the car phones being provided by Marconi. The system provided incoming and outgoing call capability. Outgoing calls were made via a rotary dial. Incoming calls relied upon a human operator determining which cell the car phone was currently within and then routing the call manually to the appropriate base station. By the mid 1960s, MTA was replaced by MTB, and because of the introduction of transistors, it was possible to design smaller phones that required less power and were cheaper to manufacture. MTB was launched in 1965; however, it soon ran out of capacity, once it was serving 660 customers.

In Finland, in 1971, the ARP (Autoradiopuhelin, "car radio phone") system was launched. It was based on a cellular arrangement of base stations, although there was no handover between cells – leaving the coverage of a cell would cause the call to drop. The first ARP mobile terminals were large and could only be fitted in a car boot, with a handset near the driver's seat. In the 1990s, handhelds were introduced for ARP, but they never became popular as true cellular systems such as NMT became more ubiquitous with more affordable mobile phones.

1.1.5 The first commercial cellular launches

By the early 1970s, both AT&T and Motorola announced plans which envisaged the development and deployment of high-capacity mobile

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telephony networks based on the cell-based structure. AT&T submitted a proposal in 1971 to the FCC for the commercialization of a nationwide cellular mobile phone system. By February of 1973, Motorola had produced a working DynaTAC (Dynamic Adaptive Total Area Coverage) portable phone prototype, which they presented to the FCC along with design details for a complete cellular network system. The FCC agreed to hold new hearings on allocating spectrum for a future cellular service. However, the process of decision making at the FCC was very slow and bureaucratic. Agreement to a trial with AT&T was reached in 1975, though approval was not granted until 1977. Further progress was stunted by the larger debate about the future of the monopoly which was AT&T.

Records suggest that the world's first commercial cellular telephone system was actually launched in Bahrain in May 1978, operating with just two cells on 20 channels in the 400 MHz band and with a capacity of 250 subscribers. Telephones were supplied by Matsushita (Panasonic), and network equipment was supplied by Cable and Wireless.

In Tokyo, an 88-cell system was launched in 1979, using Matsushita and NEC equipment. The first North American launch was in Mexico in 1981, though this only operated on a single cell.

Nordic Mobile Telephone (NMT) System – a cellular system developed by Nokia, Ericsson and others, was launched in 1981 on a small scale (20 cells) in Saudi Arabia, followed by larger Scandinavian-wide deployment in Denmark, Finland, Norway and Sweden. Because compatible systems were deployed in each of these neighboring Nordic countries, NMT was the world's first network to provide an international roaming capability. The first NMT car phones were introduced in 1982 by Nokia Corporation. Several other countries also launched cellular networks in the early 1980s, including Mexico in 1981 and the first Vodafone network in the UK in 1985 using a variant system known as TACS (Total Access Communications System), followed by a number of other European countries – each with its own incompatible variant system. Note though that all of these early cellular systems operated using car phones – the story moves back to the USA for the launch of the world's first commercial handheld mobile phone.

After many years of deliberations, agreement was finally reached on the future of AT&T, leading to its breakup into a number of smaller

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regional operating companies in 1982. With this hurdle cleared, the regional Bell operating company Ameritech began operating the first commercial cellular service in the USA on October 12, 1983, in Chicago, with other launches following rapidly. The system was the AMPS (Advanced Mobile Phone Service) analog cellular system.

For Motorola, it had been a long wait. On September 21, 1983, Motorola was granted approval by the FCC to sell the DynaTAC 8000X phone – the world's first commercial portable mobile phone, after more than ten years of research and development, and perhaps more than a 100 million US dollars of investment. Motorola had recognized the potential to utilize developments in electronics and computing years before in order to create a much more portable wireless phone. Martin Cooper, who we met at the start of this chapter, had worked closely with Motorola's industrial design director, Rudy Krolopp, and his team, in order to conceive a design for the physical shape of the phone. A number of concepts were created, and a clear winner emerged, which, as Krolopp later recalled, "We called it a shoe phone, because it sort of looked a little bit like a boot."

Motorola DynaTAC 8000X

Voted one of the ten ugliest technical products ever by *PC World* magazine in 2007, the Motorola DynaTAC 8000X was the world's first ever mobile phone, and was a truly technological and product marvel when it was first launched in 1983, due to the utility value of being able to make telephone calls whilst on the move and out and about.

In 1984, the Korea Mobile Telecommunications Company was formed, and an AMPS cellular service was launched in the same year. Manufacturing of phones soon followed, with a joint venture in South Korea between Nokia and Tandy to form the Tandy Mobira Corporation. Tandy had a network of electronics stores across the USA, and Nokia wished to enter the US market. This was South Korea's first entry into manufacturing handsets, the first baby step in the direction of what would become a

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major manufacturing base for mobile phones, with the later emergence of globally significant players such as Samsung and LG.

Back in Scandinavia, in 1987 Nokia launched its first NMT handheld mobile phone, the Nokia Mobira Cityman 900. This phone gained the nickname of "Gorba" when the then Soviet leader Mikhail Gorbachev did a photo shoot making a call from Helsinki in Finland back to his Communications Minister in Moscow. The Mobira Cityman 900 weighed 800 g and had a price tag of 24000 Finnish marks.

1.2 Generations of mobile communication capability

Before we move forward into the various generational advances from these first cellular network systems, it is worth our while to understand the key differences between the different generations or "Gs" in mobile communications. What a lot of meaning is carried in the implication of a move to "the next generation"! It was with the advent of the first digital mobile networks that the term "second generation," or 2G, was coined, and only post-rationally was the term "first generation," or 1G, applied to the preceding solutions. So it was that 2G provided a "clean slate" on which to design a new generation of cellular network systems based on advances in electronics which allowed much signal processing to be carried out by digital electronics.

The term "3G" was initially used to advent the move to systems which could support higher-speed data, and arguably to encourage national regulators to free up additional spectrum for use by future mobile communication services. However, in the meantime, a number of important incremental improvements were made to the 2G systems to support the move from traditional circuit-switched data to packet-switched data. With the birth of the World Wide Web in the early 1990s, mobile packet-data solutions became essential to provide an efficient method of carrying Internet traffic, which is itself packet-based. Having already allocated the term "3G," the industry resorted to labeling these important improvements as "2.5G" and "2.75G."

In the early 2000s the term "3G" was used to create perception in the mind of the consumer that they would be able to browse the Internet

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from their mobile phone using a high-speed data connection, much as they would from their desktop PC. Although this was technically possible, the user experience was pretty poor, and much work was still required to understand how to deliver Internet-based services and content to a mobile successfully. More of this later. After the over-hyping of the term 3G, there was caution in any use of the term 4G for a number of years, hence the use of terms such as 3.5G, 3.75G and even 3.9G! In 2010/11, US operators began to talk up the availability of so-called "4G" services to provide higher data rates and better capacity, as users migrated from feature phones to smartphones in large numbers. The major innovations brought by each generation may be summarized as in Table 1.1.

1.3 The digital revolution – 2G

With mobile phones becoming a proven commercial success by the early 1980s, plans began to be laid for successor systems. The number of simultaneous mobile phone users on the same cell – otherwise known as cell capacity – quickly emerged as a key issue as network traffic continued to grow. A successor system had to offer a significant improvement in capacity to continue to allow growth in the industry. Advances in the electronics industry, resulting in increasing computational capability and miniaturization without a corresponding increase in price, created opportunities to specify and create a significantly more advanced cellular system based on digital signal processing.

Advantages of digital over analog transmission are numerous. With rapid advances in electronics, greater levels of functionality became possible at a reducing cost. It became possible to integrate more functions onto an integrated circuit at a reduced cost and size. The move to digital provided many additional advantages, such as:

- the ability to use the available spectrum much more efficiently using modern information coding techniques;
- the ability to encrypt information, for example making voice calls secure from third-party interception;
- the ability to switch (and therefore share) frequencies more rapidly;

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Table 1.1. *Generations of mobile communication standards*

Generation	Key innovations	Examples
0G	Wireless telephony capability between a mobile (moving) handset and a base station	Military use in WWII early commercial car phone systems
1G	Use of multiple small overlapping cells, resulting in better frequency re-use between cells and a reduction in the maximum required transmit power Ability to hand-off/handover calls onto different frequencies on different cells without dropping the call	NTT (Japan) NMT (Nordic countries) AMPS (USA) TACS (UK)
2G	Move from analog to digital radio transmission technologies Secure (encrypted) voice traffic Short messaging service (SMS) Circuit-switched data services (full duplex data and facsimile) International roaming (GSM)	GSM (Europe-wide and then increasingly globally) CDMAOne (North America, South America, South Korea, Japan, China) PHS (Japan)
2.5G	Packet-switched data services, more suited to the transmission of IP (Internet) based packet data	GPRS CDMA2000 1xRTT