Part One

Mobile Clouds: Introduction and Background

1

Motivation

Inventions have long since reached their limit, and I see no hope for further development.
Julius Sextus Frontinus, highly regarded Roman engineer, 1st century A.D.

This chapter serves as a motivating introduction to the subject of this book: mobile clouds. A brief account of the evolution of mobile and wireless communications is presented from the point of view of mobile devices as well as communication networks. Mobile clouds can be considered as the result of the evolution and merging of mobile and wireless communications technologies. These initial pages will shed some light on some historical developments leading to the concept of mobile clouds.

1.1 Introduction

Untethered communications, omnipresent and fundamental in today's hyper-connected world, evolved rapidly in the last decades. The impact on our lives is so deep that it is hard to imagine how difficult it would be living now without the informational and social connectivity, freedom as well as flexibility brought by wireless communications technology. In this introduction we briefly discuss the evolutionary development of wireless communications until the present, from networks and mobile devices points of view. This overview will provide some useful and motivating background information before focusing on mobile clouds. Two evolutionary paths characterize untethered communications, the developments in *wide–area communications* on one hand, and the developments in *short–range communications* on the other hand. The former can be denominated the *mobile path*, while the latter is the *wireless path*, due to the fact that typically *mobile communications*, and *wireless communications* are the terms used for wide–area and short–range technologies, respectively. Radio broadcasting, the very first example of wide–area communications, started to be developed at the turn of the 20th century. WWI and WWII provided an immense thrust to the development of radar and communications

Mobile Clouds: Exploiting Distributed Resources in Wireless, Mobile and Social Networks, First Edition.
Frank H.P. Fitzek and Marcos D. Katz.

technology. The further developments in solid–state components resulted in miniaturization, made possible implementation of complex systems and gave birth to the era of truly portable communications equipment. The first urban mobile communications systems were deployed as early as in the latest 1940's. Single powerful base stations with high–rise antennas were initially used to provide access to areas with radius of up to some 50km. Already at that time scarcity in the available spectrum was identified as an issue and Bell Labs proposed the idea of covering large geographical regions by using a number of smaller service areas. Further developments in the upcoming decades led to the introduction of basic cellular systems for public and private use in the 1970's. Most of this pioneering work took place in the US but in the next decades Europe and Japan developed also their own commercial cellular systems. The cellular concept, based on frequency reuse in smaller coverage areas, or cells, allowed city–wide support of a large number of users. Through the 1980's until the present day four generations of cellular systems were developed, such that 2G, 3G and the rather recently introduced 4G coexist today. Requirements for higher supported data rates and network capacity led to a gradual reduction of cell sizes, typically up to few tens of kilometers in *macro–cells*, few hundred meters to few kilometers in *micro–cells* and from meters to a few hundred meters in the case of *pico–cells*. Certainly cell size is also related to mobility, large cells support higher degrees of mobility with the need for frequent handovers to adjacent cells. Providing untethered connectivity over short distances has also proved to be highly important, if not absolutely necessary, to a great deal of applications and in many practical scenarios. Over the last two decades a large number of communication technologies for short–range communications were developed fulfilling the demands for local wireless connectivity to computers, home and office appliances and other portable, movable or fixed equipment. This parallel development, the aforementioned wireless path, produced a very eclectic range of communications technologies covering from millimeters to a few hundred meters. Examples of short–range communications include wireless local area networks, (WLAN), wireless personal area network (WPAN), wireless body area network (WBAN), wireless sensor networks (WSN), radio frequency identification (RFID) and near field communications (NFC). Besides radio communication there is also optical communication, especially visible light communication (VLC). As compared to the developments in wide–area communications, focused mostly on overlay cellular networks operating on a centralized manner, short–range communications is a highly fragmented development arena, technology–, applications– and architecture–wise. The industry behind wide–area cellular and short–range communication fields are typically different. Large telecom manufactures back the former, whereas a diverse array of technology industry, with computer industry having the largest share, being behind the eclectic solutions existing for short–range communications. As we are moving towards a highly integrated mobile and communications era, the division between industry supporting cellular and short–range communications becomes blurred. Stretching from millimeters ranges of to hundreds of kilometers, wireless communications today consists of a large collection of different technologies omnipresent in our life. Figure 1.1 illustrates current representative mobile and communications approaches as a function of their typical ranges. Broadly speaking short–range and wide–area cellular communications remain today the main two approaches to untethered communications.

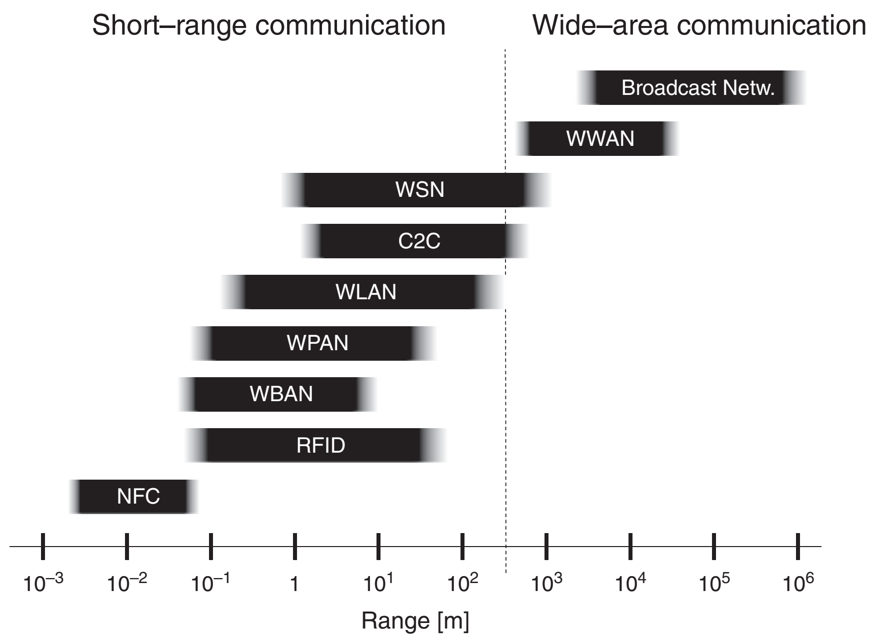

Figure 1.1 The realm of wireless and mobile communications today: from millimeters to hundreds of kilometers.

1.2 From Brick Phones to Smart Phones

Personal computers, Internet and mobile communications are among the most rapidly adopted technologies in history. In particular, the emergence and further popularization of mobile communication technologies are truly remarkable and unique achievements. Today, after a quarter of a century since the inception of mobile communications, the worldwide penetration of mobile and wireless communication devices exceeds 86% as given in [1]. Connectivity is seen today as an indispensable commodity, or even more, as a basic right of each individual. Mobile devices provide wireless access, making possible portable connectivity in most of the scenarios where people live, work and spend their free time. The outstanding development of mobile communications can be seen as the result of huge global research and development efforts by related industry, academia and regulators. Envisaging this rapid development in this area has always been a real challenge. Even the most optimistic forecasts were short to predict the colossal growth of mobile communications. In 1997 it was estimated that by 2010 there would be from one to two billion mobile subscribers [2, 3], whereas in 2006 such figure was estimated to be three billion [4]. The actual figure in 2010 well exceeded the five billions. In a few years from now (2014) the worldwide penetration is expected to reach or even exceed 100%.

These impressive figures are just one part of the story. Mobile and wireless communications have changed radically the way people communicate with each other and access information. And more changes will certainly follow. The impact of mobile communications on how people socialize, work, retrieve information, do business and entertain themselves is really enormous.

The global process of adopting mobile communications technology has been quick and its impact on individuals and the society as a whole has been profound, far beyond the initial expectations. The so far two–and–a–half decades of mobile communications development has basically spanned four mobile technology generations, known as 1G, 2G, 3G and 4G. These generations, encompassing several technologies, have coexisted and continue to coexist on a global scale. Today, 2G and 3G are the most widely used mobile technologies while 4G, being at this time rapidly deployed, will be the mainstream mobile technology in the near future. Moreover, 5G, aiming at a time-frame beyond 2020, is currently being developed. While mobile communications continues to shape the way that people live, such deep impact would have not been possible without the outstanding technical achievements that took place in the rather short mobile communications era. Among the most representative developments that occurred in the past 25 years mobile users witnessed the following technological enhancements: data rate support increased from some 100bps to 1Mbps and higher; memory onboard devices was boosted from some 1MB to 32GB and higher; weight of terminals reduced from about 5kg down to 100g and below; device size (volume) decreased from 5000cm^3 to 50cm^3; prices dropped from 5000Euro down to the range 50Euro to 500Euro; operating time saw a ten–fold decrease (1h–10h) whereas the total number of devices on a worldwide scale jumped from a few millions to nearly six billion units today.

Figure 1.2 summarizes these accomplishments by showing the approximate enhancing factors of key capabilities of mobile communications devices. Another major development in the evolution of mobile devices is the pronounced change in the nature of the mobile devices themselves. A large part of the mobile phone era has been characterized by devices designed just to provide basic connectivity (voice and data), with little or no available resources onboard

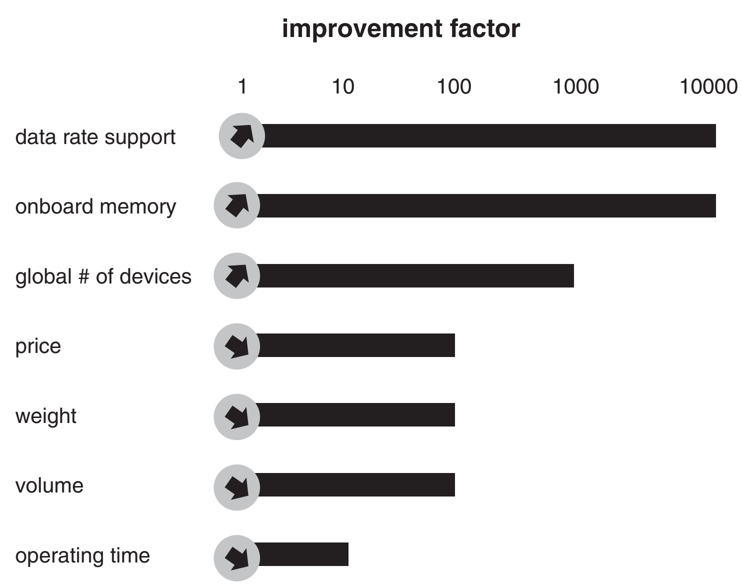

Figure 1.2 From brick phones to smart phones: mobile device evolution in the last 25 years (1985–2010).

for uses other than communications. Today, with the advent of smart phones, mobile users can enjoy sophisticated multipurpose devices, that can be seen as part of a large wireless ecosystem. Current devices have a great amount of resources on board, such as powerful processors, large mass memory, an increasingly number of sensors, a multiplicity of complementing air interfaces, advanced imaging components such as high resolution image sensors and displays. Another relatively new but immensely powerful extension to mobile phones is the development of mobile applications, *apps*, inexpensive pieces of software that can be easily downloaded bringing new capabilities to the devices. In 2011 more than 30 billion apps were downloaded into mobile phones. Mobile phones evolved from being closed–systems to become the flexible open–platforms of today. Indeed, the first generations of mobile phones were largely unchangeable, fixedly–programmed at factory, and with minimum or nonexistent support for updates or extensions. Today, the term *mobile phone* to a great extent does not accurately reflect the state of technology, *mobile device* being a more representative denomination for the current highly flexible, programmable and customizable wireless multifunction devices, that also work as mobile phones. Certainly, equally striking though less perceptible to users is the evolution undergone by the mobile communications networks, essential to match the high performance capabilities of wireless devices. Cellular networks development has been and continues to be focused on enhancing key performance figures such as supported data throughput, network capacity, quality of service, latency, reliability and coverage.

1.3 Mobile Connectivity Evolution: From Single to Multiple Air Interface Devices

In this section we shed some light on the development of the air interfaces used for mobile communications. As voice communications was the only capability of early mobile communication systems, relatively simple air interfaces were used, first based on analog designs (e.g., 1G) followed by digital approaches (e.g., 2G and beyond). The introduction of digital communications allowed naturally transfer of data, and this was first capitalized with short message services. Typically, mobile devices have had a single air interface providing just connectivity through cellular access. This simple initial approach is still widely in use today, particularly in the low–cost device segment. Such relatively simple air interface did provide low throughput connectivity, supporting initially voice and very low rate data transfer. Figure 1.3 (left side) depicts a representation of such a low–rate one–dimensional (i.e., single air interface) connectivity approach. As requirements for higher data rate support, larger coverage, and improved reliability increased, advanced air interfaces as well as networks were developed, exploiting a number of advanced techniques. These sophisticated air interfaces employed for instance different spatio–temporal processing techniques, such as diversity, beamforming and spatial multiplexing techniques. Multi–antenna approaches, known collectively as MIMO techniques (Multiple Input Multiple Output), are effective to increase data throughput, coverage and capacity, though, as a whole, the performance–complexity trade–off of MIMO techniques does not always lead to attractive engineering solutions. Moreover, advanced network architectures based on cooperative principles, e.g., multi–hop techniques, were introduced to

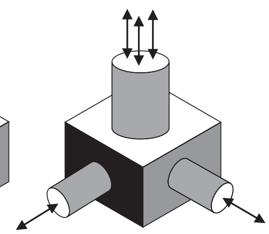

Figure 1.3 From brick phones to smart phones to the basic brick of mobile clouds: Air interface dimensionality, (a) single air interface; (b) single high–performance air interface and (c) multiple multi-dimensional air interfaces.

enhance performance and extend coverage. The generalized exploitation of radio resources (e.g., time, space, frequency) resulted in remarkable enhancements in performance at link and network levels. Figure 1.3 (middle) shows also a one–dimensional air interface approach as in Figure 1.3 (left), but supporting higher data throughputs due to the use of the aforementioned techniques.

Since the beginning of the mobile communications era, mobile devices have made use of rather simple centralized access architecture, connecting them to one or more base stations, directly or through repeaters. An interesting fact is that early wireless devices were equipped with additional wireless connectivity ports, notably optical air interfaces [e.g., Infrared Data Association (IrDA)] for very–short–range data transfer. Optical interfaces never became widely accepted by users and eventually disappeared. Today, modern devices have on board several radio air interfaces. In particular short–range connectivity is becoming a de facto capability in addition to cellular connectivity. Bluetooth and WLAN are the most representative short–range air interfaces present in current wireless devices. Air interfaces for very short–ranges, a few cm at the most, are also becoming popular, as it is the case of Near Field Communications (NFC) technology, used for private and secure data transfer between devices or to access local information on the spot.

Different air interfaces integrated into a mobile device play different roles and typically an air interface is used in a particular scenario or with a given type of application. Cooperation between air interfaces is used in a rather simple and direct way, for instance by allowing seamless switching between two access technologies, an approach known as vertical handover. Toggling from one air interface to another can be driven by one or more events, such as channel and network conditions, mobility, coverage and others. However, the presence of several air interfaces on board mobile devices has not yet being exploited at its full potential. Dynamic and rich cooperation between complementing air interfaces opens up countless new opportunities for wireless and mobile networks to improve performance, to use resources more efficiently and to create new ways to exploit distributed resources. Cooperative approaches involving rich collaboration between cellular and local networks are classified in this book under the generic name of mobile clouds. Figure 1.3 (right) illustrates the principle of a wireless device equipped with several air interfaces, providing multidimensional connectivity across

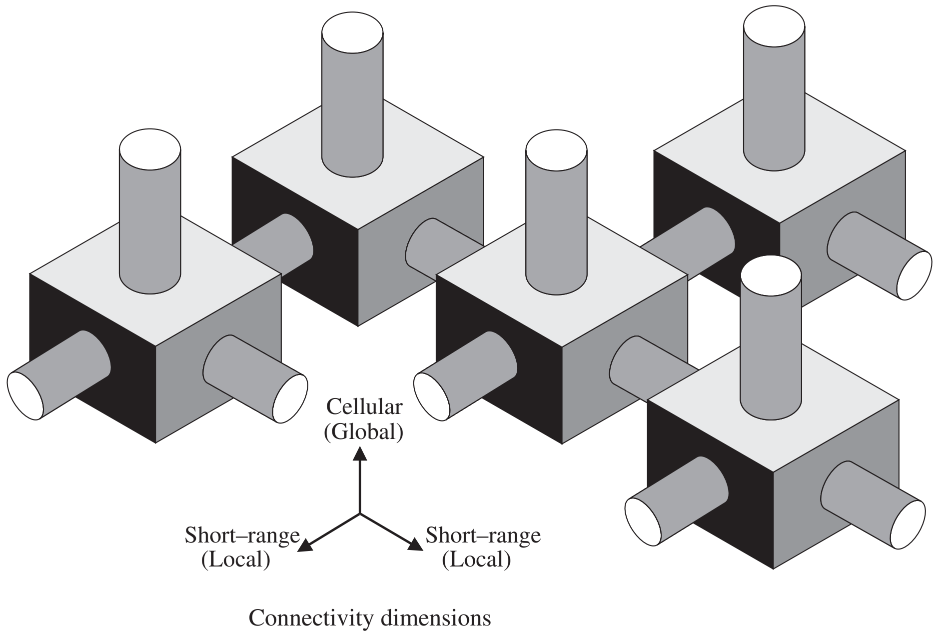

Figure 1.4 Multiple wireless connectivity (local and wide/global), the principle exploited by mobile clouds

cellular networks, local access points as well as local networks through short–range Device–to–Device communications. This represents a modern multi–air interface mobile device, providing multidimensional connectivity in the cellular (vertical) and short–range (horizontal) domains.

Figure 1.4 illustrates conceptually a mobile cloud as composed of several wireless devices (or generally speaking nodes with multiple air interfaces) that can be locally interconnected as well as can be connected to base stations or access points. This is a clear departure from the typical way to access information, or to establish connections between nodes. Indeed, the wireless network shown in Figure 1.4 is neither a conventional cellular system, nor an ad hoc network, but it combines characteristics of both. From the architecturally standpoint, the structure of Figure 1.4 retains both the centralized topology of cellular networks and the distributed topology of ad hoc networks. The composite architecture of the mobile cloud makes this approach very flexible and efficient to share resources, such as radio resources and others, like device resources. This book will discuss and investigate mobile clouds detail, considering their potentials, technical advantages, novel applications, enabling technologies, challenges and visions.

A growing trend, approximately originated at the turn of this century, is to integrate wireless communications functionalities into other devices than mobile phones. Today a great deal of portable computers, office and home appliances, cameras and cars offer wireless connectivity. Moreover, the proliferation of tiny add–on adapters using universal ports (e.g., USB–Wi–Fi, USB–Bluetooth) makes it possible to provide wireless connectivity to an even larger array of equipment. Today, in most environments where mobile users spend their time there is already a dense network of operating wireless nodes. A given mobile user is quite often surrounded by a considerable number of other wireless communications enabled devices. This is particularly true in urban environments. Certainly, as time goes by, the network of wireless nodes will become even denser, and wireless nodes will be available in virtually any environment. Wireless World Research Forum (WWRF) [5] predicts that by year 2020 there will be some seven trillion wireless devices across the globe, that is, on average one thousand wireless devices around each inhabitant. Most of these devices are expected to provide short–range connectivity, and many of them will be just passive air interfaces, like RFID tags. Still, it can be said that in most of the typical places where people spend most of their time there will be considerable numbers of other wireless communications enabled nodes with which cooperation can be established. This is a fundamental point to be exploited by mobile clouds, the wireless interaction with nodes in the immediate neighborhood together with the possible connectivity to other wireless or mobile networks. As it will be seen later in this book, the way that nodes interact and cooperate depends on many factors, including the relationship between the users behind the nodes, node capabilities and many others.

It is worth noticing that multiple wireless connectivity as shown in Figure 1.4 can be realized in many ways. Today's prevailing technology, integrating multi–standard (multi–chip) air interfaces into mobile device, is of course well suited to create the multiple connectivity approach of Figure 1.4. However, future mobile devices may have a single reconfigurable transceiver that can be readily configured on–the–fly according to a particular standard, or even as multiple air interfaces simultaneously. The upcoming LTE–A technology is an example of the developments in this direction, as it defines a single air interface supporting both cellular and Device–to–Device connectivity.

1.4 Network Evolution: The Need for Advanced Architectures

Wireless and mobile networks have steadily evolved over the past decades. This is the result of continuous R&D and huge investments by the telecoms industry and network operators, to fulfill the increasing demands and expectations of users. Improving data rates, coverage and capacity were the most important driving goals shaping this evolution. Spectral– and energy–efficiency become also important design goals for networks and mobile devices following the advent of broadband services, the rapidly growing population of users, and the massification of advanced mobile devices.

From the network architecture point of view the same topologies developed many decades ago are still in use today. Centralized access has been the key topology of cellular networks, while local networks have used either distributed or centralized topologies. These are relatively simple, well studied and widely implemented solutions. In recent years cellular network architectures have adopted simple forms of cooperation by the addition of relaying nodes between base stations and mobile devices. The architecture of cellular networks is basically deterministic, the same access topology is used regardless of the fluctuating radio environment, dynamics of the mobile devices and changing requirements of users. Local networks are by design more flexible, allowing ad hoc networking, and involving diverse types of topologies, that can be adopted depending upon particular requirements and available nodes at a given time. The stringent requirements on performance and radio resource utilization for future wireless and mobile networks call for novel networking approaches, exploiting opportunistically the fluctuating availability of network and device resources in an also changing radio environment. Conventional cellular networks lack of this flexibility, while local networks are designed with a more adaptive topology in mind. Mobile clouds, the key topic of this book, bridge cellular networks with ad hoc local networks by combining both approaches into a composite centralized–distributed topology that can react opportunistically to the changing environments and requirements. Mobile clouds offer a novel, flexible topology with an unprecedented potential not only for wireless and mobile communications but in general for exploiting opportunistically distributed resources.

1.5 Conclusion

This chapter described the state of the art and the evolution path of mobile communication systems. The number of mobile devices will increase significantly and the current mobile communication architecture will reach its limits soon. This advocates the need for mobile clouds, which will be described in the following chapters in detail.

References

[1] ITU World Telecommunication. ICT Indicators Database. http://www.itu.int/ITU-D/ict/statistics/at_glance/KeyTelecom.html, 2013.
[2] M.H. Callendar. IMT-2000 (FPLMTS) Standardization. Presented at the ITU Malaysia Seminar, Kuala Lumpur, March 1997.
[3] The UMTS Market Aspects Group. UMTS Market Forecast Study, 1997.
[4] Report by Market Intelligence Center (MIC), 2006.
[5] Wireless World Research Forum (WWRF). WWRF web page. http://www.wireless-world-research.org/.