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Operating Mobile Broadband Networks

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1.1. The Challenge of Mobile Traffic Growth

The optimization of cellular network performance and the maximization of its efficiency has long been an objective of wireless network providers. Since the introduction of GSM in the late 1980s, the growth of traffic (and revenue per user) over wireless networks as the first 2G and 3G networks were deployed remained positive and relatively predictable. For those networks, voice and messaging services such as Short Message Service (SMS) and Multi-media Messaging Service (MMS) were dominating traffic. However, in the first decade of the twenty-first century, the deployment of high-performance wide-area wireless packet data networks, such as 3GPP HSPA and 3GPP2 HRPD, has combined with advances in Digital Signal Processing (DSP) capability, multi-media source coding, streaming protocols and low-power high-resolution displays to deliver the so-called smartphone. This device has fundamentally changed the trajectory of traffic growth over broadband wireless networks.

In June 2010, The Nielsen Company reported ([1], Figure 1.1) an annual increase between Q1-2009 and Q1-2010 of 230% in average smartphone data consumption. Nielsen further reported that some users were approaching 2 GB per month in total data usage, and that the top 6% of smartphone users were consuming nearly 50% of total data bandwidth. Therefore, as more users emulate the behavior of leading adopters, further growth in per-user data consumption is expected to follow. Most significant of all, from the perspective of future growth, Nielsen estimated that the penetration rate of smartphones into the US market was only 23%. Indeed, of those users, almost 1/4 generated zero data traffic, while 1/3 had simply not subscribed to a data plan at all. This suggests a latent demand for data connectivity and that networks are only beginning to see the onset of smartphone-induced load.

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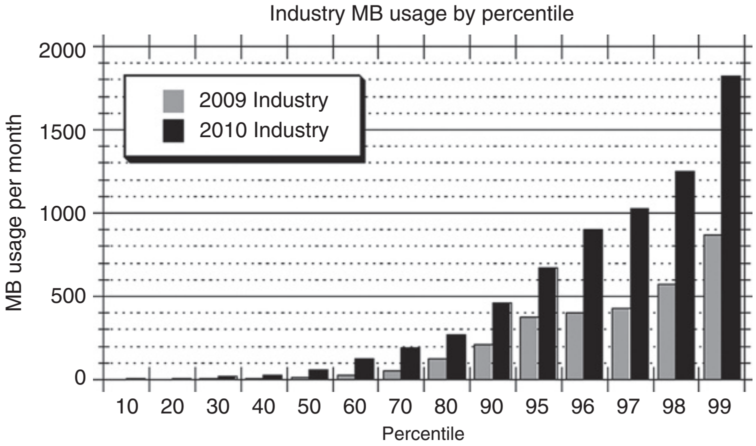

Figure 1.1 2009 and 2010 smartphone data usage distribution. Reproduced by permission of © 2010 The Nielsen Company.

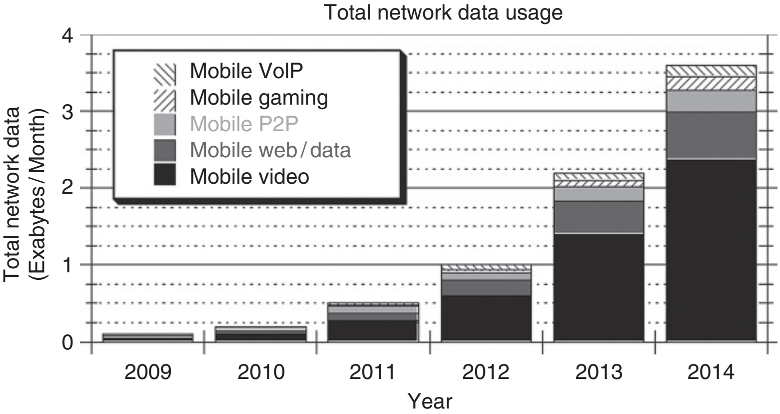

Figure 1.2 Total wireless mobile network traffic growth. Reproduced from © 2010 Cisco VNI Mobile.

The Nielsen Company's data is generally consistent with that reported by major network operators, particularly with respect to the wide distribution of user data consumption rates. For example, in June 2010, AT&T reported [2] that while the least active 65% of AT&T's smartphone subscribers used, on average, less than 200 MB of data per month, the top 2% of subscribers used more than 2 GB.

Although AT&T did not comment on future network traffic growth, others such as Cisco Systems have done so [3]. In Cisco's view, total wireless mobile network traffic growth (Figure 1.2) will exceed a Compounded Annual Growth Rate (CAGR) in excess of 100% per annum in the period 2010–2014, with video traffic providing as much as 2/3 of total traffic. In other words, on an annualized basis, total network traffic will double until at least the middle of the decade. This suggests that, as compared to 2009, if not prevented by

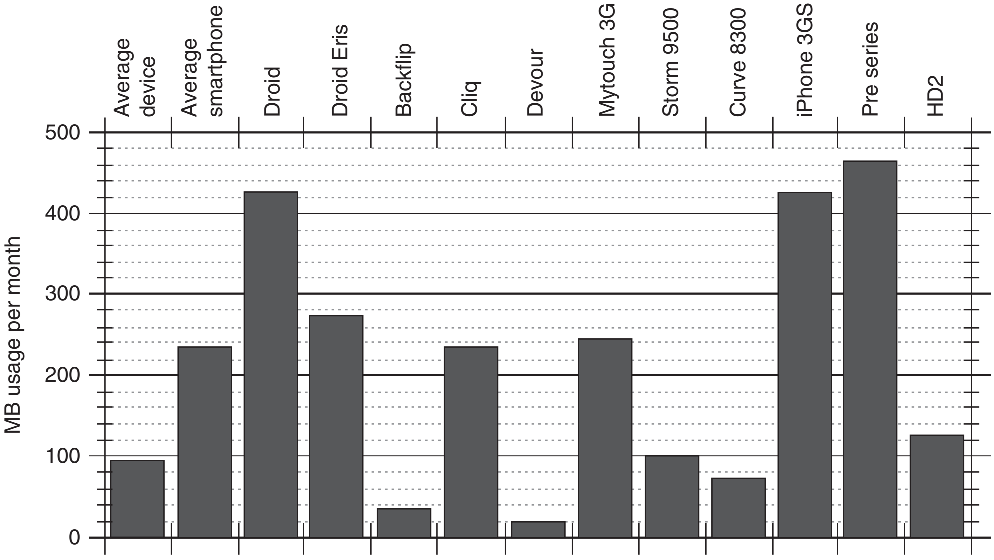

Figure 1.3 Traffic generation by smartphone type. Reproduced by permission of © 2010 The Nielsen Company.

factors such as limited-data subscription plans or insufficient spectrum, a 64-fold increase in total network traffic will result by 2015.

1.1.1. Differences between Smartphones

Even amongst those users who are equipped with smartphones, there is a wide disparity in data usage. There are a number of factors which influence the amount of data generated per device, including the user interface, applications available to the user (driven by operating system popularity), subscriber data plan, configuration of services using data link push and keep-alive techniques, etc. It is possible, however, to establish general trends by looking closely at measured data volumes on a per device basis. For example, in the 2010 Nielsen data depicted in Figure 1.3, along with the Palm Pre, the market-leading Motorola Droid and Apple iPhone 3GS devices both generated very significant data volumes, consistent with the rich set of experiences enabled by each platform. On average, both of these leading devices were generating around 400 MB of monthly data traffic per subscriber. This is well in excess of the average behavior of all devices (Average device) of around 90 MB per month, and even the average smartphone monthly consumption of 240 MB.

Figure 1.3 further suggests that the core capabilities of smartphone devices are also important in establishing data consumption. Table 1.1 lists selected capabilities of influential smartphone devices launched in 2009/10, including a subset of the most significant devices from Figure 1.3. A comparison of the Motorola Droid and Cliq devices shows a progressive increase in application processor, screen resolution and multi-media capabilities that would tend to drive the difference in user data consumption for each device observed in Figure 1.3.

Table 1.1 Contemporary smartphone capabilities

Device	Screen		Application Processor	Memory RAM, Flash, Max. µSD	Camera	Connectivity
	Size	Res.				
Motorola Cliq	3.1″	480×320	Qualcomm MSM7200 528 MHz	256 MB, 512 MB, 32 GB	5MP	UMTS-HSPA, EDGE, 802.11b/g
Motorola Droid	3.7″	480×854	TI OMAP 3430 600 MHz	256 MB, 512 MB, 32 GB	5MP	1xRTT, DO-A, 802.11b/g
Motorola Droid 2	3.7″	480×854	TI OMAP 3620 1 GHz	512 MB, 8 GB, 32 GB	5MP	CDMA 1x, DO-A, 802.11b/g/n
Motorola Droid X	4.3″	480×854	TI OMAP 3630 1 GHz	512 MB, 8 GB, 32 GB	8MP	CDMA 1x, DO-A, 802.11b/g/n
Apple iPhone 3GS	3.5″	480×320	Samsung ARM	256 MB, 16/32 GB, N/A	3MP	UMTS-HSPA, EDGE, 802.11b/g
Apple iPhone 4	3.5″	960×640	Samsung ARM	512 MB, 32 GB, N/A	5MP	UMTS-HSPA, EDGE, 802.11b/g/n
HTC Droid Eris	3.2″	480×340	Qualcomm MSM7600 528 MHz	288 MB, 512 MB, 32 GB	5MP	1xRTT, DO-A, 802.11b/g
HTC HD2	4.3″	480×800	Qualcomm Snapdragon 1 GHz	448 MB, 512 MB, 32 GB	5MP	UMTS-HSPA, EDGE, 802.11b/g

Source: Motorola 2010

The same general trend is observable in Table 1.1 for vendors other than Motorola such as Apple and HTC. It is worth noting that Table 1.1 spans a relatively short device launch period of only approximately two years.

1.1.2. Driving Data Traffic – Streaming Media and Other Services

The advent of streaming media services such as those offered by Pandora and YouTube has had a major impact on device data consumption.

Internet audio streaming (Internet radio) using, amongst others, streaming MPEG-1 Audio Layer-3 (MP3), Windows Media Audio (WMA), Flash Video (FLV) or Real Audio formats, and using protocols such as Real-time Transport Protocol (RTP), Real Time Streaming Protocol (RTSP), Real Time Messaging Protocol (RTMP), User Datagram Protocol (UDP) and HyperText Transfer Protocol (HTTP), has been deployed on the wired Internet since the late 1990s. Since 2005, however, despite the increasing enforcement of royalty-driven limitation on streaming, the advent of genre-based streaming services such as Pandora or even subscription services such as XM Radio Online has further increased the popularity of this type of service.

Depending on service type, server-client rate adaptation strategy and subscription policy, typical data rates for audio streaming services range from 56–192 kbps, yielding a per user consumption rate of ~25–85 MB/hr. This significant data consumption rate is most impactful when combined with the observed user behavior of invoking an audio streaming service and then permitting the stream to continue as a background audio service for an extended period (often several hours in duration) while executing other tasks.

Video streaming services represent another major source of network load. Services here are generally very well known, and include YouTube, Hulu, TV.com, etc. YouTube, which is a typical example of such a service, generally uses FLV or MP4 containers, plus MPEG-4 AVC (H.264) video encoding with stereo audio encoded using Advance Audio Coding (AAC). Typical served rates are 85–500 kbps (i.e. ~38–220 MB/hr), with a limit on total content duration (e.g. 10 min) and size (e.g. 2 GB) depending on the relationship between the entity uploading the source content and the streaming service provider.

Recently, the aforementioned services have become available for the wireless Internet due to the rich set of features implanted by smartphones. As a consequence, the large data volumes associated with these data services have to be carried by wireless radio networks, causing mounting pressure on the available wireless infrastructure.

1.2. Capacity and Coverage Crunch

Mobile data traffic is growing extensively and it is projected that a 64-fold increase in total network traffic will result by 2015 as discussed in Section 1.1. This explosive growth in mobile broadband places serious demands and requirements on wireless radio networks and the supporting transport infrastructure. The most obvious requirement is the massive capacity expansions and the necessary coverage extensions that need to be provided while meeting the required Quality of Service (QoS).

In general, traffic growth is healthy if network operators can charge for it proportionally and if they can provide sufficient network capacity to cope with that growth. It is worthwhile noting, however, that these capacity expansions are required at a time when operators' Capital

Expenditure (CAPEX) and Operational Expenditure (OPEX) budgets are limited and Average Revenue Per User (ARPU) growth is saturated.

The following sections provide an overview of techniques and solutions available to help wireless operators address the challenges associated with the explosive traffic growth.

1.3. Meeting the Challenge – the Network Operator Toolkit

Fortunately, network operators have a wide variety of techniques available to deal with the challenge of mobile data growth. First, operators can employ economic incentives to modify user behavior by adjusting tariff structures. Another approach is to improve network capacity through the deployment of advanced Radio Access Technologies (RATs), such as 3GPP Long Term Evolution (LTE). This approach, and the significant CAPEX associated with it, is often combined with the acquisition of new spectrum. Interest in the use of WiFi companion networks and offloading techniques has recently grown, along with preliminary deployments of innovative network elements such as femto cells or home base stations. The optimization of protocol design and traffic shaping methods, together with the deployment of advanced source coding techniques, has recently become popular. Finally, and most significantly for the purpose of this book, there has been intensive interest in the optimization of existing radio network assets and there has been huge interest in expanding the scope of Self-Organizing Networks (SON) to cover 2G and 3G. This last approach has the added attraction of relatively low capital and operational investment.

1.3.1. Tariff Structures

With the increasing adoption of smartphones, the era of unlimited data plans may be coming to an end. For example, in June 2010, AT&T publicly announced [2] two limited data plans: DataPlus and DataPro. Under the AT&T DataPlus plan, users were offered a total of 200 MB of data for US$15 per month, with an additional 200 MB of data available for use within the billing cycle for a further US$15 fee. Under the companion DataPro plan, 2 GB of data were included in the basic US$25 fee, with a further 1 GB available for use within the billing cycle at the cost of an additional US$10. New Apple iPad users were mapped to the AT&T DataPro plan, and the antecedent unlimited plan was phased out.

AT&T is, of course, not unique in taking this approach, and similar trends can be seen in other networks and geographic regions. For example, in June 2010, O_2 announced [4] that new and upgrading users would be mapped to a selection of data plans offering between 500 MB and 1 GB per month of data usage for £25–60, with additional data available for approximately £10 per GB, depending on the selected data bolt-on product. Notably, however, in Asia, after a period of expansion for data-limited plans, competitive pressure is re-establishing unlimited data offerings, at least for a period, by operators such as SK Telecom [5].

Limited data plans apply generically to all traffic transported by the network. However, new opportunities may also be emerging for network operators seeking to limit specific traffic flows from/to certain Internet Protocol (IP) addresses and port numbers, for technical or business reasons. These may include, for example, ports used by streaming media services or

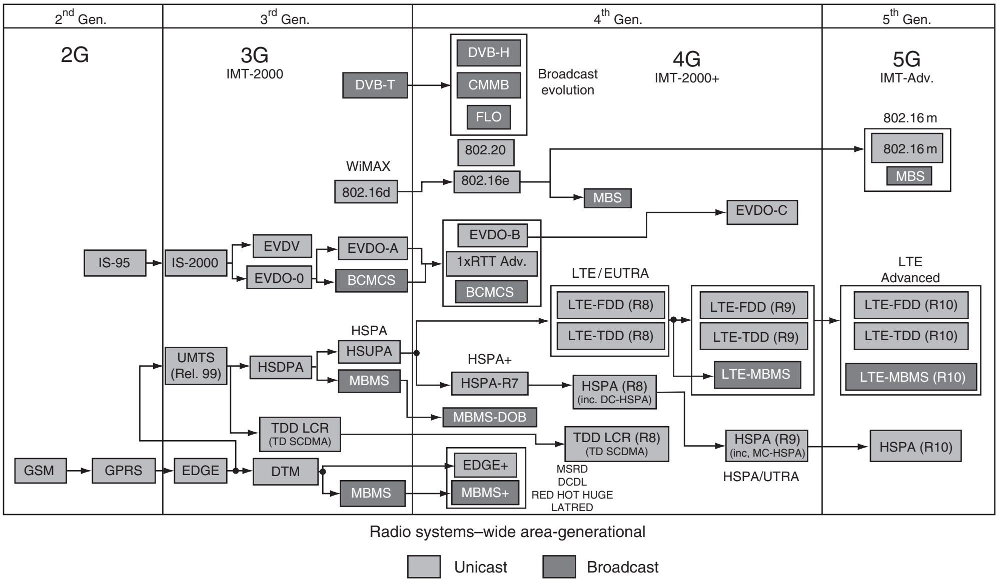

Figure 1.4 Evolution of WAN radio access. Reproduced by permission of © 2010 Motorola.

other data-intensive traffic sources. Alternatively, network operators may seek to limit traffic originating from particular applications, or indeed traffic exchanged with competing service providers could be limited or mapped to lower QoS classes. These approaches are the subject of intensive regulatory scrutiny. In the US, for example, the April 2010 Federal Court ruling on so-called net neutrality [6] may encourage more efforts by network operators to intervene in traffic flows, but further legislative or regulatory activity is very likely.

1.3.2. Advanced Radio Access Technologies

With the exception of green field deployments, the opportunity for network operators and device vendors to migrate towards network RATs with improved spectral efficiency is heavily dependent on existing commitments and compatible legacy technologies. This is illustrated in Figure 1.4, which shows the respective evolution of wide area RATs from the roots of GSM, CDMA and IEEE 802.16d into HSPA+, LTE, EV-DO and WiMAX. As the figure shows, the strategic landscape surrounding broadband wireless is in some ways becoming simpler with the deployment of 4G networks. For example, at present, the EV-DO family of technologies appears to have limited prospects for widespread deployment of the EV-DO Revision B (DO-B) and EV-DO Revision C (DO-C) variants, and consequently, although EV-DO technology will remain operational for many years, unless there is some shift in the strategic landscape, the evolutionary track for EV-DO is effectively terminating. Similarly, with the commencement of work in 3GPP [7] to support deployment of LTE in the U.S. 2.5 GHz band, further commitment to WiMAX 2.0 may be limited, although Q3-2010 commitments by Indian operators following the Indian 3G and Broadband Wireless Access (BWA) spectrum auctions to both WiMAX and

Table 1.2 HSPA+ and LTE evolution – device capability summary

Functional Support			3GPP HSPA			3GPP LTE		
Function	Units	Sub-Func.	Rel-7	Rel-8	Rel-9	Rel-8	Rel-9	Rel-10 (LTE-A)
Component Carrier Bandwidth	MHz	DL	5	5	5	{1.4, 3, 5, 10, 15, 20}	{1.4, 3, 5, 10, 15, 20}	{1.4, 3, 5, 10, 15, 20}
		UL	5	5	5	{1.4, 3, 5, 10, 15, 20}	{1.4, 3, 5, 10, 15, 20}	{1.4, 3, 5, 10, 15, 20}
Multicarrier	#Carriers	DL	1	2	2 (Non-Adj.)	1	1	5
		UL	1	1	2 (Adj.)	1	1	2
Link Bandwidth	MHz	DL	5	10	10	20	20	100
		UL	5	5	10	20	20	40
Max. Modulation	N/A	DL	64-QAM	64-QAM	64-QAM	64-QAM	64-QAM	64-QAM
		UL	16-QAM	16-QAM	16-QAM	16-QAM	16-QAM	64-QAM
MIMO	#Streams/Carrier	DL	2	2	2	4	4	8
		UL	1	1	1	1	1	4
Max. Data Rate (Terminal Capability)	Mbps	DL	28.0 (Cat. 16, 18)	42.2 (Cat. 20)	84.4 (Cat. 28)	10.3, 51, 102, 151, 302	10.3, 51, 102, 151, 302	10–1000
		UL	5.7 (Cat-6, 2ms)	11.5 (Cat-7, 2ms)	11.5 (Cat-7, 2ms)	5.2, 25.5, 51, 75	5.2, 25.5, 51, 75	5–200
Broadcast & Multicast		N/A	MBMS	MBSFN, DOB	MBSFN, DOB	N/A	EMBMS	EMBMS+

Source: Motorola 2010

Table 1.3 Comparison of HSPA+ and LTE spectral efficiency

	Downlink Spectral Efficiency (bps/Hz/cell)				
Deployment Scenario	HSDPA 1×2			LTE 1×2	LTE 2×2
Channel: TU 3 km/h	RAKE	MMSE	MMSE RxDiv	MMSE RxDiv	MMSE RxDiv
Urban Macrocell: 500 m SiteSite Dist.	0.30	0.59	1.09	1.23	1.83
Urban Macrocell: 1700 m SiteSite Dist.	0.29	0.58	1.05	1.3	1.75
Hotspot: 100 m SiteSite Dist.	0.30	2.42	NA	3.3	6.53

Source: Motorola 2010

to LTE Time Division Duplex (TDD) mode suggest that the long-term future of WiMAX may be undecided.

All of this appears to position 3GPP LTE, both Frequency Division Duplex (FDD) and TDD variants, and 3GPP HSPA+ as the critical Wide Area Network (WAN) RATs for the next decade, and even beyond, as enabled by the International Mobile Telecommunications – Advanced (IMT-Advanced) process, provided regional technology programs remain aligned to these central threads.

Focusing further on HSPA+ and LTE, it should first be noted that there is no formal definition for HSPA+. Since the High Speed Uplink Packet Access (HSUPA) companion specification to the 3GPP Release 5 High Speed Downlink Packet Access (HSDPA) was completed in 3GPP Release 6, it is reasonable to categorize networks or devices supporting one or more HSPA features from 3GPP Releases 7 through Release 9 to be HSPA+. Practically speaking, however, and leaving aside some relatively minor layer 2 efficiency improvements and the useful device power-consumption enhancements offered by the Continuous Packet Connectivity (CPC) feature, the major HSPA+ capacity-enhancing components offered by Release 7 are downlink dual-stream Multiple Input Multiple Output (MIMO) and 64-Quadrature Amplitude Modulation (QAM) capability (see Table 1.2), thus resulting in support for peak rates in excess of 10 Mbps. Notably, the deployment of MIMO-capable HSPA+ networks and devices appears increasingly unlikely due to infrastructure and legacy device equalizer limitations, leaving 64-QAM as the principal Release 7 HSPA+ enhancement.

This permits the comparison of spectral efficiency of a 10 MHz LTE Release 8 network and an HSPA+ network, which appears in Table 1.3. Here, Release 8 HSPA+ dual-carrier feature has been incorporated into HSPA+ results in order to permit direct comparison of the same 10 MHz FDD pair. It can be seen from the results that the performance of HSPA+ networks is comparable to that of LTE with the deployment of dual-port receivers denoted by 1×2 in Table 1.3 (one transmit antenna at the base station and two antennas at the handset providing receive diversity).

This defines the strategy of many 3G operators today – to execute selected upgrading of HSPA infrastructure, including the critical backhaul capacity elements, to support HSPA+ and hence to support device rates up to 21 Mbps (HSDPA Category 14) or more, while seeking to

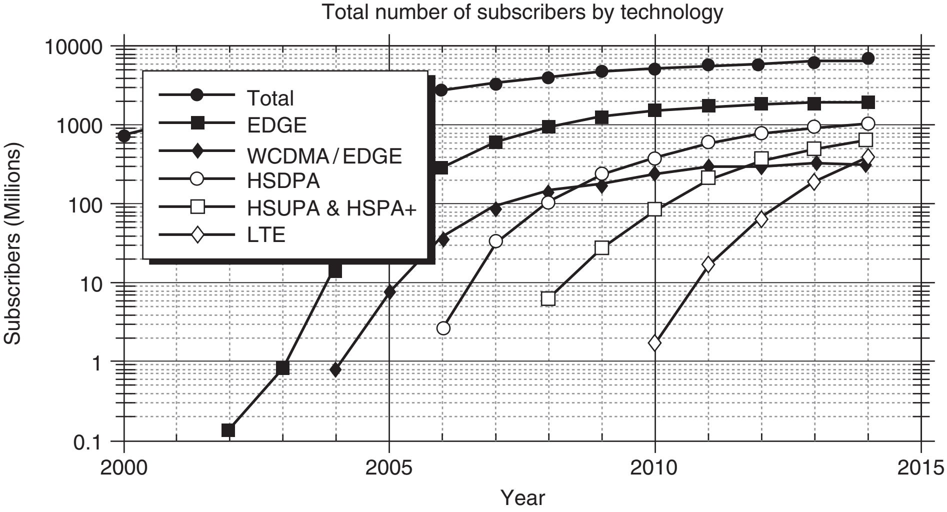

Figure 1.5 Total subscriber device capabilities by year. Reproduced by permission of © 2009 Strategy Analytics.

deploy LTE at the earliest date consistent with LTE device maturity and cost competitiveness. Here, it is worth noting that (as indicated in Figure 1.5) the total installed base of devices supporting at least one LTE band will not represent a truly significant fraction of total mobile devices before 2015. Accordingly, it is reasonable to assume that the migration of data traffic to higher performance wide area RATs will be gradual, and it may take until the end of decade 2010–2020 before the majority of worldwide operational terminals are LTE-capable.

1.3.3. Femto Cells

A key component is the emergence of femto cells (or home base stations) deployed either in enterprise or domestic environments. Although deployments of femto cells conformant to conventional macro-cellular core specifications are completely feasible, several enhancements to basic femto operation have been specified by 3GPP and other standards development organizations (including WiMAX Forum and Femto Forum). In 3GPP, this has included the definition of Closed Subscriber Groups (CSGs) who have been granted access to restricted femto cells, methods for easily identifying femto cells during radio resource management procedures (e.g. via CSG-specific synchronization sequences), and enhanced mobility procedures for handing-off devices more reliably into a CSG femto cell. Upper-layer support for Local IP Access (LIPA) to local network resources has been added to 3GPP Release 10. Nevertheless, despite significant potential, the rollout of femto cells for domestic environments, such as Vodafone's Sure Signal or AT&T's Femtocell brands, has had a limited impact from the perspective of network load management and reduction. Rather, femto cell marketing to date has emphasized enhancement of coverage-limited network access to voice services. Accordingly, with limited adoption so far, and reuse of operators' core licensed spectrum required in any case, femto cells are unlikely to make a significant contribution to network unloading before 2012–13.

1.3.4. *Acquisition and Activation of New Spectrum*

The identification, clearing and activation of new spectrum for mobile services, and the efficient refarming of existing spectrum, are problems receiving intense scrutiny by regulators in all three International Telecommunications Union (ITU) regions.

In ITU Region 2 (Americas), in March 2010, the United States announced, as part of the National Broadband Plan (NBP) [8], the intention to make available 500 MHz of additional spectrum for mobile broadband services by 2020, with 300 MHz to be made available by 2015. Assets in this case include a 20 MHz allocation in the 2.3 GHz Wireless Communications Service (WCS) band, disposition of the remaining 10 MHz (Block D) of spectrum from the 700 MHz auction of 2008, Federal Communications Commission (FCC) Auction 73, and a further 60 MHz of spectrum comprising mainly elements of the Advanced Wireless Services (AWS) band (generally, in the range of 1755–2200 MHz). In addition, a further 90 MHz of Mobile Satellite Service (MSS) spectrum from L- and S-bands would be made available under Ancillary Terrestrial Component (ATC) regulation (where devices supporting terrestrial broadband service must also support a satellite component). Perhaps most significant is the possibility of an additional 120 MHz of spectrum to be reallocated from broadcast use to mobile services.

In ITU Region 1 (Europe, Africa and Middle East), there is also considerable activity leading to new spectrum deployments. One example is the auction of 190 MHz of spectrum at 2.6 GHz (generally, in conformance to the band structure envisaged by the ECC/DEC(05)05 European directive) conducted in 2008–2010 by Norway, Sweden, Finland, Germany, Netherlands and Denmark, with other European countries expected to follow in 2010 or 2011. Perhaps most significant, however, is the German auction in May 2010 of 360 MHz of spectrum located mainly in the 800 MHz and 2.6 GHz bands yielding 2×10 MHz each at 800 MHz for Vodafone, T-Mobile and O_2 plus awards at 2.6 GHz to Vodafone (2×20 MHz FDD, 25 MHz TDD), T-Mobile (2×20 MHz FDD, 5 MHz TDD), O_2 (2×20 MHz FDD, 10 MHz TDD) and E-Plus (2×10 MHz FDD, 10 MHz TDD).

In ITU Region 3 (Asia), a similar narrative has evolved. In China, for example, band proposals for 700 MHz mobile operation (698–806 MHz) include options for allocation of the entire band for unpaired operation (i.e. TDD mode), or a split in allocation between paired (FDD, 698–746 MHz) and unpaired (TDD, 746–806 MHz) modes. It is unlikely, however, that this spectrum will be released before 2015. More immediate opportunities for new spectrum in China include 100 MHz available in the 2300–2400 MHz band plus up to 190 MHz of spectrum in the 2.6 GHz band (2500–2690 MHz). Of these, the 2300–2400 MHz spectrum was designated for unpaired operation as early as 2002, and has been used successfully for LTE-TDD trials at the Shanghai Expo of 2010. However, coexistence concerns with other services may limit future deployment in that band to indoor use. This has led to increased interest in the 2.6 GHz band, where, amongst other possibilities, alignment with the European or U.S. 2.6 GHz band plans has been considered, along with an alternative all-TDD designation favoring LTE-TDD mode. Similar commitment to release spectrum, albeit on a smaller scale, has emerged for the same bands in India, resulting most recently in the Indian 3G and BWA spectrum auction.

Clearly, the acquisition of new spectrum offers a major opportunity to enhance network capacity. Notably, however, the acquisition of spectrum can be highly capital-intensive. For example, the German auction of May 2010 yielded total bid amounts of €4300 million.

Further, the activation of new spectrum can involve costs to relocate users or services, and the provision of additional radio hardware and transmission backhaul at sites where the new spectrum is to be activated. All of this suggests that, while new licensed spectrum is a critical component to resolving network capacity shortages, it is generally a costly option, available only on a medium- to long-term basis.

1.3.5. Companion Networks, Offloading and Traffic Management

The cost of new licensed spectrum has led to renewed interest in the resources offered by unlicensed spectrum, such as the US 2.4 GHz Industrial, Scientific and Medical (ISM) band, the 5 GHz National Information Infrastructure (NII) band and the 700 MHz Television White Space (TVWS) band. Many major network operators now lease access to WiFi from WiFi network service aggregators (where one or more distinctive WiFi hotspot networks are gathered under a single brand and are accessible using a single set of access credentials), or operate public WiFi hotspot networks that are cobranded as companion networks to the operator's primary wide area broadband network. Authentication protocols such as Wireless Internet Service Provider roaming (WISPr) are usually applied, in combination with either Wired Equivalent Privacy (WEP) or, more frequently, WiFi Protected Access (WPA) and WiFi Protected Access 2 (WPA2) authentication methods using user- or operator-supplied credentials stored on the device or UICC-based[1] credentials. Significantly, access to such WiFi networks is increasingly offered without additional charge as an element of a broader wide area data plan.

Almost all contemporary smartphones support WiFi connectivity. This allows operators to offload a significant portion of growing data traffic from their primary WAN network onto their WiFi network. Leaving aside the consequent increased load on WiFi networks and the resulting interference, there are a number of obstacles here. First, enabling the device's WiFi interface on a continuous basis can lead to elevated device electric current drain and reduced battery life, with consequent user dissatisfaction. Second, the spatial density of the operator's hotspot network is often not sufficient to provide service coverage on a contiguous basis, despite hotspot collocation with transport or social centers (e.g. airports, cafes, etc.). For example, in one Chicago suburb, the spatial separation between WiFi hotspots associated with one 3G network was around 4 km, roughly twice that of the companion 3G network intersite separation, and therefore the opportunity to conveniently connect to a hotspot can be limited. Finally, some operator services, such as operator branded messaging or media services, referred to here as Carrier Branded Services (CBS), must have access on a trusted basis to the operator's core network in order to execute authentication functions.

The problem with low battery life can be overcome by using appropriate power management techniques in both the WiFi associated and non-associated states. The low spatial density of WiFi hotspots implies that many or even most data-offloading WiFi connections will be established in the user's home or enterprise. This raises questions about the capability[2] of those networks. Answers for these questions can be found through privacy-appropriate surveying techniques[3]. Summary results of a public WiFi Access Point (AP) beacon survey conducted by

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[1] Universal Integrated Circuit Card

[2] For example, support for 802.11b or 802.11n, supported data rate, type of security support (if any), etc.

[3] The survey was conducted by examining only the system information in the 802.11 management frames transmitted by all nonhidden WiFi access points.

Table 1.4 Public WiFi AP survey summary – Q2-2010

AP Mode	%	Band	%	Bandwidth	%	802.11 Type	%	Security Mode	%
Ad Hoc	3	2.4GHz	98	20 MHz	95	b	7	Open	20
Infrastructure	97	5GHz	2	40 MHz	5	g	78	WEP	37
						n	15	WPA	24
								WPA2	19

Source: Motorola 2010

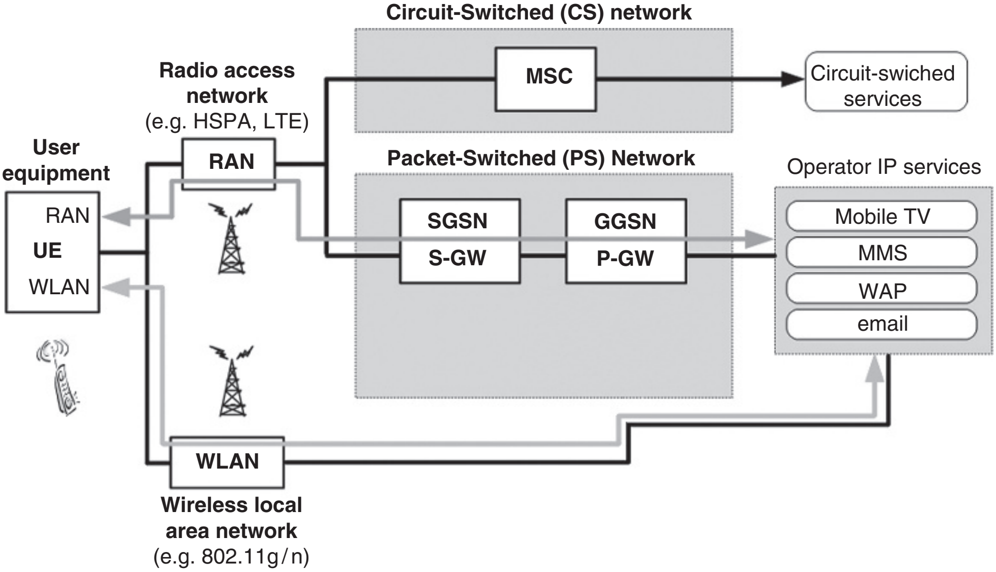

Figure 1.6 Offloading architecture – Type I. Reproduced by permission of © 2010 Motorola.

Motorola in Q2-2010 appear in Table 1.4. It can be seen that although more than 90% of public WiFi APs conform to the 802.11g amendment, few 802.11n APs were deployed at the time of the survey. Significantly, most APs were deployed in the 83 MHz of spectrum available in the 2.4 GHz ISM band, which, for practical purposes, can support a maximum of three 20 MHz 802.11 carriers. Almost no APs were operational in the 5 GHz band, which, at least in the US, offers a total of 550 MHz of spectrum, suggesting that, as smartphones increasingly support 5 GHz WiFi access, this approach to network offloading has real prospects for growth.

Finally, the difficulties related to accessing the operator's core network on a trusted basis can be resolved by using appropriate routing and tunneling techniques. There are several approaches to achieve this. In one of them, illustrated in Figure 1.6, the device maintains WAN (i.e. 3G/4G) and WiFi connections simultaneously. This permits the bulk of non-CBS data to transfer over the WiFi connection, while access to CBS data may occur over the secured WAN network. An evolution of this approach appears in Figure 1.7. In this architecture, the operator has invested in additional network-edge routers capable of terminating a secure

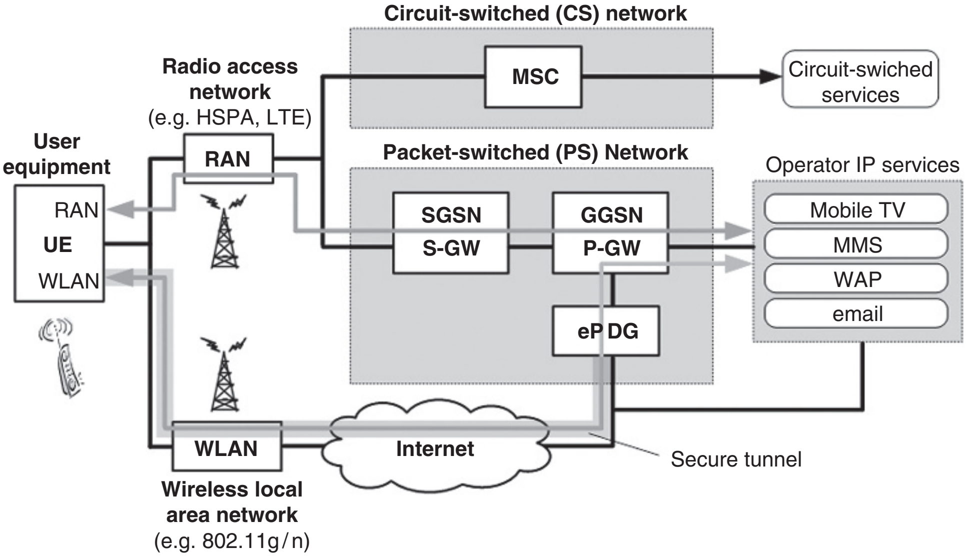

Figure 1.7 Offloading architecture – Type II. Reproduced by permission of © 2010 Motorola.

tunnel originating in the device over the unsecure WiFi network. As a result, additional CBS-specific traffic may enter the operator's core network over the unsecure WiFi connection, with the remaining traffic terminating directly in the Internet.

1.3.6. Advanced Source Coding

New approaches to source coding also offer the prospect for improvements in network efficiency. Traditionally, cellular systems have looked into speech coding efficiency as a baseline measure of source coding performance. Here, notwithstanding the evolution of the CDMA Enhanced Variable Rate Codec (EVRC) family to the EVRC-C variant, the migration of CDMA operators to LTE appears likely to bring EVRC evolution to a close. At the same time, the need for improved voice quality means that a number of 3G operators, most notably T-Mobile International and France Telecom/Orange, are now migrating from the well-established 3GPP-specified Adaptive Multi-Rate NarrowBand (AMR-NB) codec (covering the audio range of 200 Hz to 3.5 kHz) to the evolved AMR WideBand (AMR-WB/G.722.2) codec (50 Hz to 7.0 kHz). This brings a corresponding increase in bit rate from 5.9–12.2 kbps (AMR-NB) to 12.65 kbps (AMR-WB) and above.

Fortunately, recent work in ITU-Telecommunication (ITU-T) SG-16 [9] on the G.718 codec, which can maintain bitstream compatibility with AMR-WB, indicates it is possible to achieve quality levels normally associated with AMR-WB at 12.65 kbps by using G.718 with 8 kbps. This is, in part, the motivation for the 3GPP Enhanced Voice Service (EVS) work [10]. Significantly, however, the 3GPP EVS specification is unlikely to be complete before 2011 and is unlikely to be operational before 2012. Accordingly, in the medium-term, speech source coding rates will not diminish in the period up to 2012, but may well increase as AMR-WB is deployed.

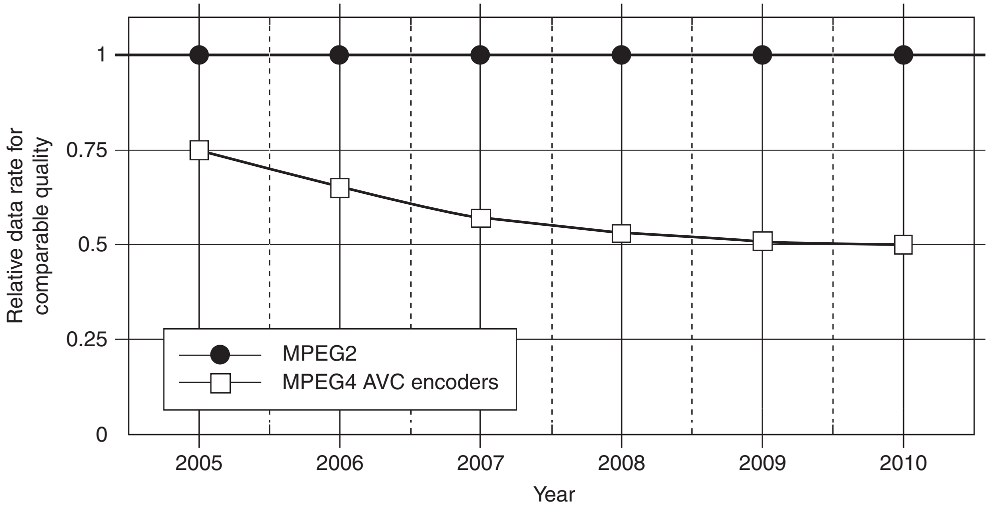

Figure 1.8 MPEG-4 and MPEG-2 quality versus time. Source: Motorola 2010.

When operating in the range of 32–64 kbps, the performance of the G.718 and EVS codecs begin to overlap with that of the AAC codec family specified by the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC), most notably the AAC Low Delay (AAC-LD) and AAC Enhanced Low Delay (AAC-ELD) variants. Recent operator assessments (e.g. [11]) suggest, however, that neither of these codecs offer efficiency advantages over G.718 or the emerging EVS specification, with proprietary codecs such as SiLK (Skype) or Speex reported to operate at significantly poorer efficiencies. For medium- to high-rate audio coding applications (i.e. bit rates in the range of 32–256 kbps), smartphones such as the Motorola Droid X or the Apple iPhone make available MP3, AAC and AAC+ codecs. At these audio coding rates, there is little evidence at present that work in ISO/IEC or 3GPP will lead to significant improvements in efficiency in the near-term. Rather, the trend towards super-wideband (50 Hz to 14 kHz) and full-band (20 Hz to 20 kHz) codec operation, and potentially towards support for surround sound in WAN networks [12] suggests that in the next decade improved audio source coding will not lead to significant reduction in network load, but rather will emphasize improved quality and enhanced services.

Clearly, however, from the traffic growth information presented above, more efficient encoding of video traffic would have the greatest impact on total network load. Again, there appears to be limited opportunity for significant fundamental improvements in the near term. This is largely due to diminishing incremental improvements in the performance of the ITU/ISO/IEC MPEG-4 AVC/H.264 video codec (Figure 1.8).

Most significantly, while there is a clear recognition that further improvements in video coding efficiency are essential, it will clearly take time to achieve this. For example, ISO/IEC MPEG and ITU-T Video Coding Experts Group (VCEG) have established the Joint Collaborative Team on Video Coding (JCT-VC) to deliver a High Efficiency Video Coding (HEVC/H.265) specification [13], with the goal of achieving roughly a twofold improvement in encoding efficiency for the same or lower computational complexity. Subjective assessment, however, of initial proposals for HEVC commenced in March 2010 [14], with the date for completion of the specification targeted at Q3-2012. This suggests the earliest possible widespread deployment date of fully compliant HEVC codecs would be 2013.

At the same time, the advent of AVC/H.264-enabled 3D-video will tend to push streaming rates even higher. Moreover, and unrelated to 3D-video, smartphone and converged computing or tablet device (e.g. iPad) screen resolutions and rendering capabilities continue to increase. For example, the Motorola Droid X smartphone introduced in July 2010 offers a 4.3” (10.9 cm) Wide Video Graphics Array (WVGA) (480×854) display combined with a High-Definition Multi-media Interface (HDMI) port and the ability to render 720p AVC/H.264 content. The converged computing Apple iPad (launched in April 2010) correspondingly offers a 9.7” (24.6 cm) display supporting 1024×768 resolution, and AVC/H.264 video up to 720p format at 30 frames per second.

Accordingly, as such devices further penetrate broadband wireless markets, and in the obvious absence of a radical improvement in video coding efficiency, operators will continue to migrate network servers towards more efficient use of existing codec techniques (such as AVC/H.264) [15]. Opportunities for such advanced streaming procedures include proprietary methods such as Microsoft Smooth Streaming, Apple HTTP Live Steaming (HLS) and standardized approaches such as ongoing efforts in Open IPTV Forum (OIPF) and 3GPP [16]. Nevertheless, while such approaches will improve video rate adaptation (to better suit channel conditions or access technology) and will offer trick play features in an efficient way, they will not fundamentally reduce the growth of video traffic, although they may offer enhanced means of maintaining adequate video quality within specific data-rate constraints.

1.4. Self-Organizing Networks (SON)

All capacity expansion techniques that have been discussed so far are valid paths, and operators’ strategies need to rely on them to cope with growing data volumes and demanding customer expectations (in terms of QoS and service cost). Nonetheless, the techniques that are available today involve outstanding capital outlays, and therefore it is worth reflecting on whether the current infrastructure is being operated at its full performance potential before considering network expansions or evolutions.

Going back to basics, it is important to remember that, for example, the Universal Mobile Telecommunications System (UMTS) is a complex technology in which coverage, capacity and quality are deeply coupled to each other. There are many optimization levers that currently remain untouched or, at best case, fine-tuned at network level, i.e. with the same settings for all different cells. The bottom line is that, even though a UMTS network may be delivering acceptable Key Performance Indicators (KPIs), most likely there is still room for increasing its capacity, just by carefully tuning the different settings on a cell-by-cell basis.

The idea to carry out adaptive network optimization on a per sector (or even per adjacency) basis is part of the SON paradigm, which has been defined around a set of clear requirements formulated by the Next Generation Mobile Networks (NGMN) Alliance [17]. The objective of the SON proposal is to enable a set of functionalities for automated Self-Organization of LTE networks, so that human intervention is minimized in the planning, deployment, optimization and maintenance activities of these new networks. Subsequently, the support for this new network management paradigm is being translated into concrete functionalities, interfaces and procedures during the standardization of Evolved Universal Terrestrial Radio Access Network (E-UTRAN) in 3GPP.

The SON Use Cases can be structured in different ways. As will be discussed in Chapter 2, one of the possible high-level classifications is the following:

- Self-Planning: derivation of the settings for a new network node, including the selection of the site location and the specification of the hardware configuration, but excluding site acquisition and preparation.
- Self-Deployment: preparation, installation, authentication and delivery of a status report of a new network node. It includes all procedures to bring a new node into commercial operation, except for the ones included in the Self-Planning category, which generate inputs for the Self-Deployment phase.
- Self-Optimization: utilization of measurements and performance indicators collected by the User Equipments (UEs) and the base stations in order to auto-tune the network settings. This process is performed in the operational state, which is defined as the state where the Radio Frequency (RF) interface is commercially active (i.e. when the cell is not barred/reserved).
- Self-Healing: execution of the routine actions that keep the network operational and/or prevent disruptive problems from arising. This includes the necessary software and hardware upgrades or replacements.

Whereas current commercial and standardization efforts are mainly focused on the introduction and Self-Organization of LTE networks, there is significant value associated with the extension of the scope of Self-Planning, Self-Optimization and Self-Healing to cover GSM/GPRS/EDGE and UMTS/HSPA RATs. The implications of multi-technology SON are massive. On one hand, the adoption of a multi-technology approach allows operators to completely transform and streamline their operations, not only applying an innovative, automated approach to the new additional LTE network layer, but also extending the automation-related operational savings to all RATs, thereby harmonizing the whole network management approach and boosting operational efficiency. On the other hand, the availability of a multi-technology SON solution can lead to more comprehensive, holistic and powerful optimization strategies that deal with several RATs simultaneously.

Practical experience shows that the application of 3G SON technologies in current UMTS infrastructure can yield a capacity gain of 50% without carrying out any CAPEX expansion.

1.5. Summary and Book Contents

In summary, as smartphones continue to proliferate, there is a clear and present need to improve the efficiency and capacity of contemporary broadband networks. Fortunately, there is a wide variety of options available to network operators, ranging from evolution in network technology such as improved backhaul and the use of enhanced RATs such (e.g. HSPA+ and LTE), through acquisition of new spectrum, offloading to companion networks (e.g. WiFi) and the application of advanced source coding along with traffic shaping methods.

Equally clearly, however, no single approach will resolve the challenge caused by the exponential growth in network traffic. Critically for the present purpose, the approaches discussed in Section 1.3 are either capital intensive (e.g. new spectrum acquisition or network deployment) or are associated with extended time horizons (e.g. new source coding technology breakthroughs) or both. Therefore, SON techniques and functions have a unique role to play. They can be deployed today, at moderate to low cost, in contemporary 2G and 3G networks to increase operational efficiency with little or no delay. SON techniques will, of course, evolve to support LTE.

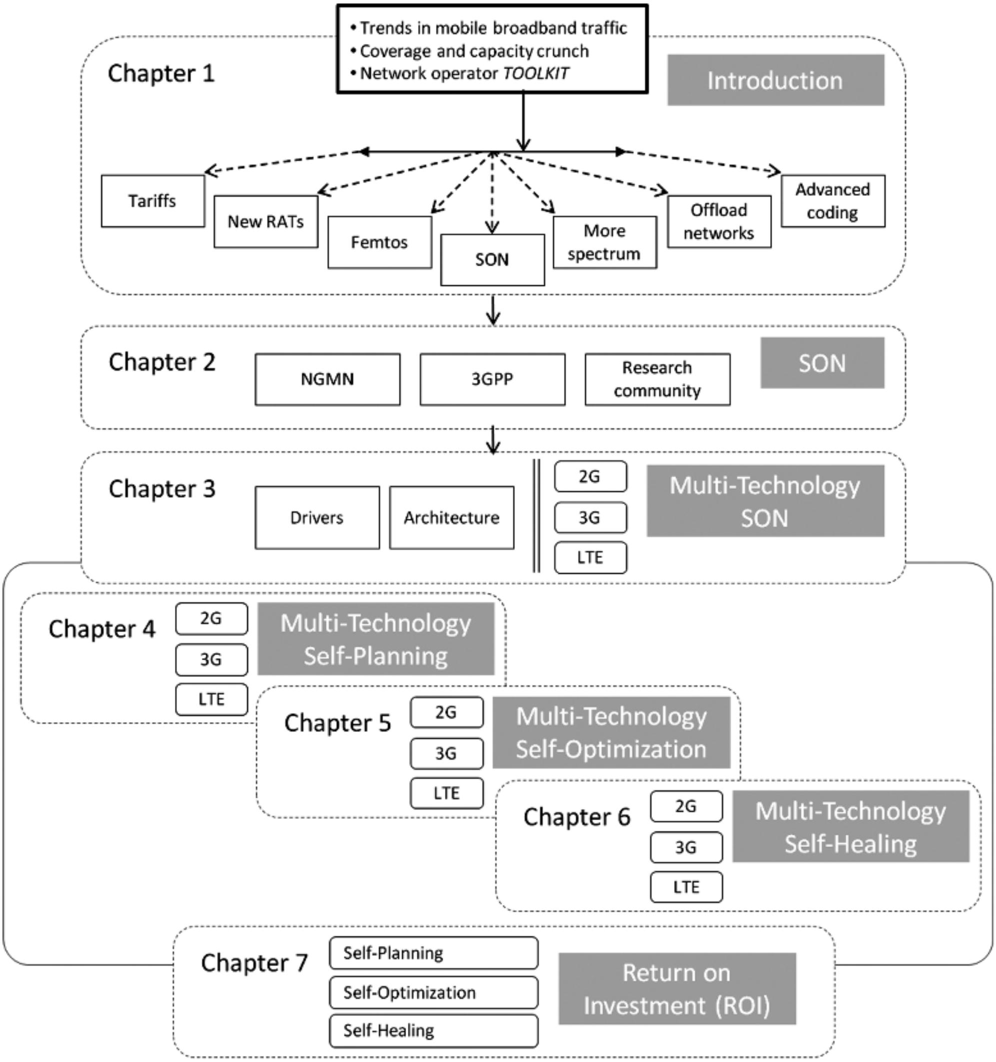

Figure 1.9 Book contents map.

The main purpose of this book is to describe multi-technology SON for 2G, 3G and LTE, and to cover the best practice deployment of Self-Organizing Networks that support multi-vendor and multi-technology wireless infrastructures. This will be done mainly from a technology point of view, but also covering some critical business aspects, such as the Return On Investment (ROI) of the proposed SON functionalities and Use Cases. Figure 1.9 provides a conceptual map summarizing the contents of the book. Chapter 2 provides an overview of the SON paradigm covering NGMN objectives and the activities in 3GPP and the research community. Chapter 3 covers the multi-technology aspects of SON, from main drivers to a layered architecture for multi-vendor support. Chapters 4, 5 and 6 cover the multi-vendor and multi-technology (2G, 3G and LTE) aspects of the Self-Planning, Self-Optimization and Self-Healing of wireless networks, respectively. Finally, critical business aspects, such as the ROI of the proposed SON functionalities and Use Cases are presented in Chapter 7.

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