Roadmap to Personalised Liquid Bandwidth

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Abstract - This paper addresses a roadmap to a personalised liquid bandwidth future. It covers the sequential steps and corresponding measures to be taken. As wireless personal area networks will support different radio technologies, we believe deployment of short range mini cells is a first step towards this future liquid bandwidth stage. Generally, the higher the offered bandwidth, the shorter the radio ranges will be. Mini cells could provide offload possibilities and wireless indoor access to the end user at higher speeds than today's 3G outdoor solutions. Bitrates comparable to xDSL or cable come within reach. Operators could initially benefit by offloading large amounts of non real-time data traffic via these mini cells, thus avoiding scaling up their macro radio networks. A second step lies in redefining the radio planning and provisioning process. Automated and balanced deployment of mobile, wireless and fixed access capacity requires a novel integrated complementary access planning framework. As a next step we foresee additional real time sniffing functionality to be put in place. This, in the long term, will enable a next societal stage in which end users' supply and demand can instantaneously be matched. The enabling infrastructure could be featured by personalised services over optical circuit-switched networks.

Keywords: liquid bandwidth, complementary access, access planning tool, roadmap, trans-sectoral innovation.

Introduction

Currently three major trends in telecommunications are commonly recognised:

- increasing demand for personalised high QoS services,
- the tendency to enjoy these services wirelessly ,
- ongoing growth of bandwidth need.

These trends force us to redefine the capabilities and properties of a future personalised liquid bandwidth infrastructure. Particularly its access part will change substantially. Currently at the fixed access plane consumer market requirements are met by deploying coax cable or ADSL technology. Considering xDSL, during this decade copper and its capabilities will be pushed to its very limits. As the next incremental step (VDSL/Fiber to the Curb) would imply thousands of street cabinets, we envisage another future infrastructure. It should be based on a combination of macro and mini radio cells, being interconnected by fixed end-to-end optical switched capacity [1]. This future image is summarized in Fig. 1, metaphorically showing a complementary wireless and wired access structure.

Water in this picture symbolises information flowing in two directions: raining down into sinks and spraying up via fountains. Water travelling via air represents the wireless part. Water condenses and rains down from the customer clouds. The size of the water drops represents the required bandwidth. The rain is collected into sinks with differently sized surfaces (radio cells). The water generally flows to the nearest sink at the border of the fixed drainage system. Underground the collected streams of water are multiplexed, aggregated and directed across the transport network, via huge optically switched rivers in many colours of light. As the availability of clean water is increasingly precious, so is the reliability of a liquid bandwidth infrastructure enabling high QoS services.

Customer needs will dominantly influence the next generation infrastructure properties. The convergence of fixed, wireless and mobile features in the telco's portfolio is ongoing. The enabling technology is likely to follow. Figure 2 describes the fundamental differences in the Fixed DNA and the Mobile DNA. Today's Wireless DNA can be considered to be somewhere in between, i.e. having radio capabilities on the one hand, but lacking mobile handover capabilities on the other hand. The Next Gen DNA obviously is an optimized combi-

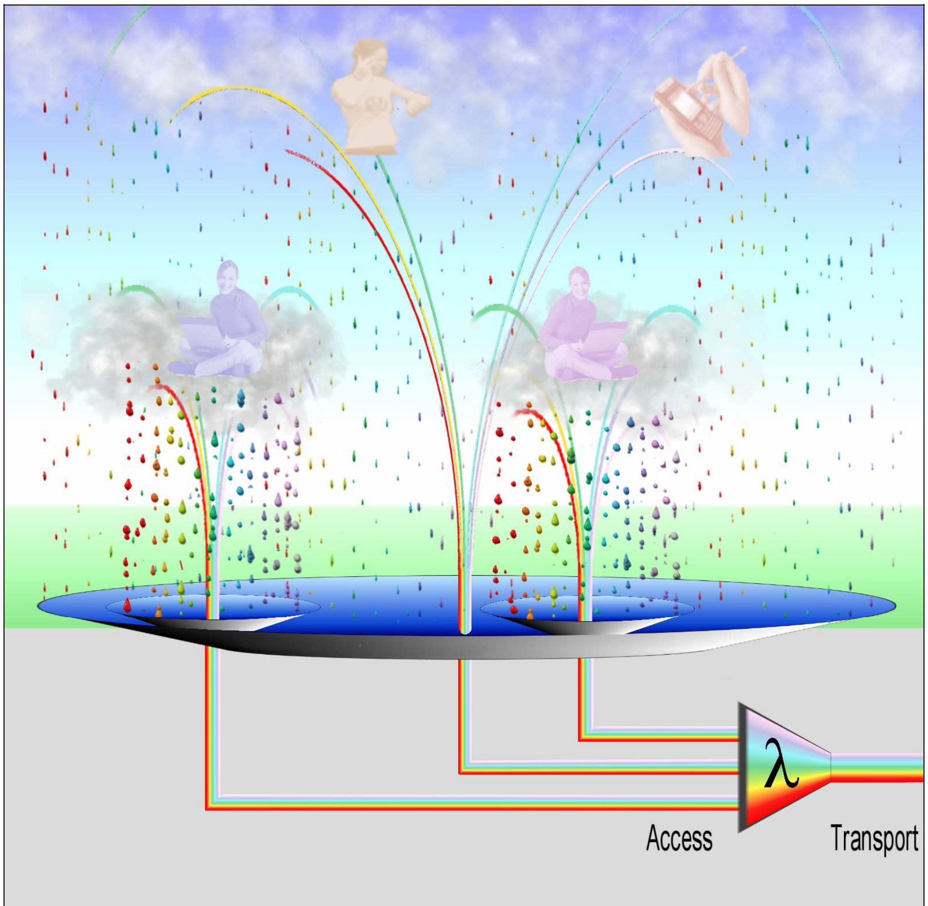

Fig. 1. A colourful personal liquid bandwidth metaphor.

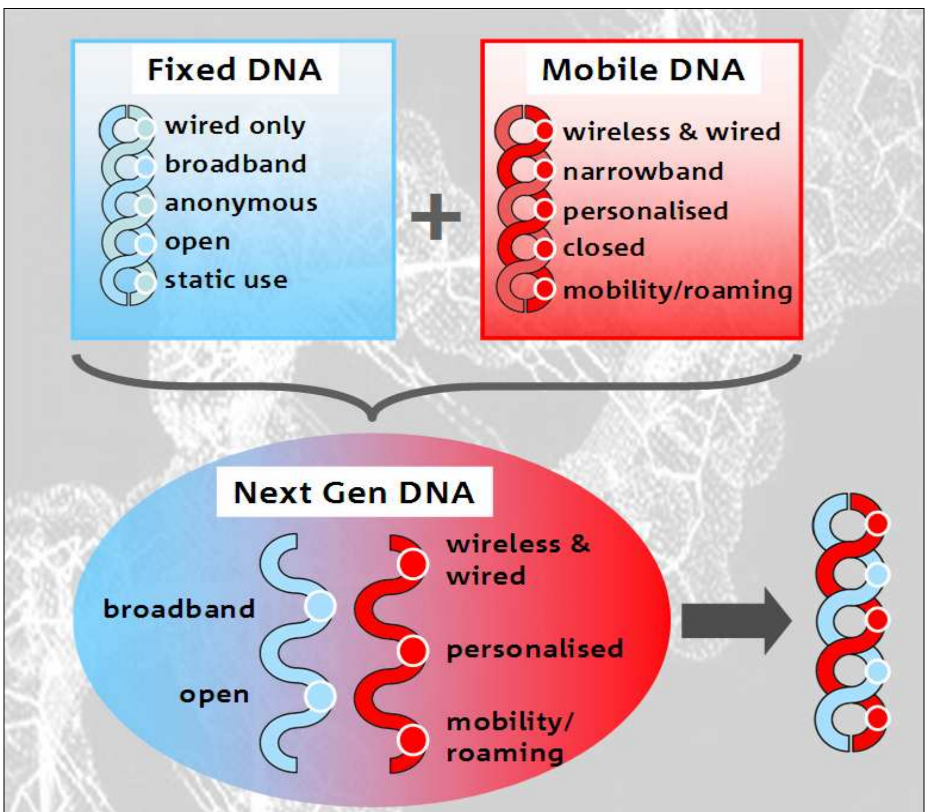

Fig. 2. Customer needs drive the Next Gen DNA selection.

nation, in which attractive properties are selected and obsolete properties will be rejected.

In general today's fixed connections are not personalised and do not support mobility.

Their static and anonymous DNA properties no longer seem to be future-proof. Here mobile network technology and for instance its robust personalised SIM functionality, proves to be superior. The end user can enjoy the offered services any place, at any time.

On the other hand today's mobile networks tend to be less open than fixed networks for business reasons. Closed business models are likely to disappear. As one single operator or service provider cannot meet all customer desires, it has to open its walled garden to welcome partners. From this perspective a wholesale enabled infrastructure requires openness.

After the Internet boom mobile operators have been acting more carefully, balancing their profitability and total cost of ownership. This status quo is slowing down the mobile broadband innovation process. Compared to fixed data speeds, mobile data speeds can be considered to be narrowband. As mobile data usage is growing worldwide, in this perspective the bandwidth provisioning process needs to be enforced with complementary options, in order to meet future bandwidth needs.

Taking the above into account the Next Gen infrastructure DNA selection below is the most likely set for survival in an extremely competitive landscape.

Explanation Complementary Access

We expect the telecommunications infrastructure (2010–2015) to become a Fixed Mobile converged infrastructure, stimulating bandwidth consumption.

Radio bandwidth usage strongly varies in a geographic sense. Current 3G networks are over-dimensioned due to traffic uncertainty and initial coverage reasons. Knowing that bandwidth needs will increase this over-dimensioned inefficient reality cannot be perpetuated. A requirement for shorter radio ranges will arise, leading to the conclusion that complementary access is a future neces-

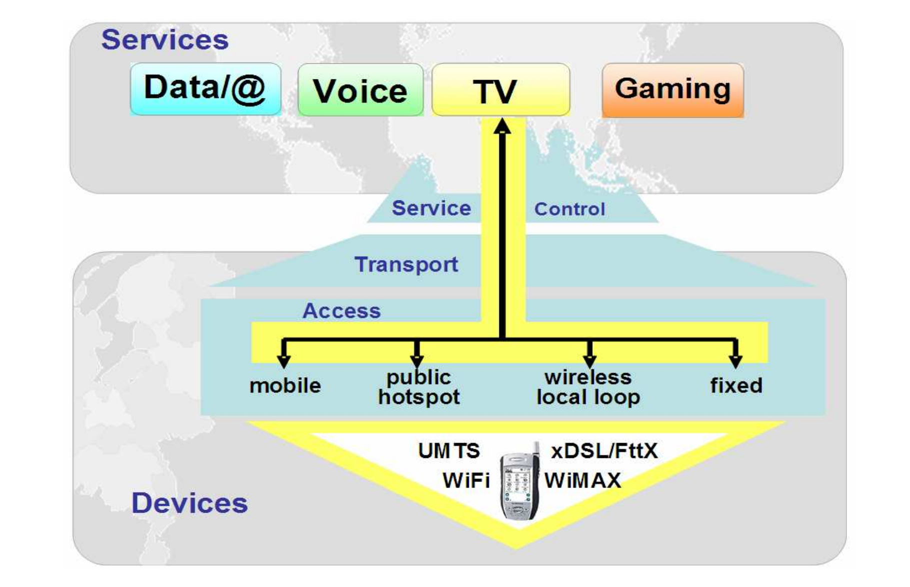

Fig. 3. Example complementary access to a TV service.

sity. Macro outdoor radio cells will be combined with various mini radio cells which can be deployed both indoor and outdoor. In this paper we define complementary access as all functions, together providing end user equipment (personal area networks, handhelds, devices, terminals, etc.) access to a set of service platforms via two or more different access networks.

A generic transport plane will bridge the access plane and the service plane. Figure 3 shows an example of a TV service that can be reached using multi-interface devices handling streaming sessions over various access technologies. Similar examples could be depicted where the end user can reach (and supply) data/Internet, voice or gaming services via the same transport and complementary access layer. Note the (graphic) presentation of the services can be diverse, depending on the type of end user equipment.

When establishing a complementary access network, integrated network planning and provisioning has to be performed over all involved access technologies both at the customer side and the transport side. Examples of involved technologies are: UMTS/ HSPA, GPRS, GSM, WiFi (IEEE 802.11 family), WiMAX (IEEE 802.16 family), Ethernet (9802.1D/Q), ATM, xDSL and FttX. Another boundary condition for an operational complementary access network, is the availability of QoS management mechanisms on all involved layers.

Complementary Access Hierarchy

Each technology has its typical range, varying from a satellite able to cover almost half the earths' surface, to several meters covered by a Bluetooth device. As standardisation proceeds towards 4G the functional capabilities of the different technology families increasingly converge. Thus a hierarchical classification of these (access) technologies based on the way they are deployed, seems more appropriate.

Especially concerning mini radio cells, several terms are in use today e.g., "femto cells", "pico cells", and "micro cells". Many types of solutions are announced or have been introduced recently, often combining different radio technologies (e.g., WiFi/GSM).

In a four-tiered hierarchy model [2] the majority of the radio implementation solutions can be captured. One fixed and three different mobile and wireless access planes together form a converged fixed-mobile infrastructure. From a top-down perspective it consists of:

A ***macro plane,*** consisting of outdoor radio cells, having a cell radius in the order of magnitude of *several km's,* which can be deployed on top of a tower or tall building for wide area coverage, serving a great many users on the way.

A ***micro plane,*** generally consisting of outdoor radio cells, having a cell radius in the order of magnitude of *several hundreds of metres*, can be deployed on rooftops or streetlights. They are to be used for high-traffic hot zones and can serve tens of users simultaneously. For business market purposes taylor-made indoor solutions can be envisaged too.

A ***pico/femto plane,*** consisting of indoor or outdoor radio cells, having a cell radius in the order of magnitude *up to a hundred metres,* can be deployed under the rooftop. Less than 10 (broadband) users can be served simultaneously.

A ***fixed plane,*** consisting of a densely distributed high-capacity wired access network.

Technologies and their Properties

This decade a large scale transition from "narrowband circuit technology to broadband packet technology" is ongoing in the fixed plane. Due to increasing bandwidth need, optical technology is emerging in the fixed access plane (replacing copper). Thus, circuits are likely to come back, because an optical connection (i.e., wavelength, colour or Lambda) can be considered as a circuit. A revolutionary approach is to revert to circuit switching in casu to all optical switching and routing in order to obtain highly efficient routing and fast transmission [1].

We now limit our scope of attention to (expected) capabilities and properties of the following technologies: WiFi, WiMAX, EDGE, UMTS, HSPA and new LTE technology currently being standardised. Table 1 gives an overview of some technical characteristics for each of these technologies[1]. The characteristic features gathered in Table 1 serve for a functionality and performance comparison between technologies.

Today concerning mobility support, only GSM, GPRS, EDGE, UMTS, HSPA and Mobile WiMAX are designed to perform seamless handovers and roaming, a requirement originating from the voice business. Services like TV, video streaming, and Internet are mainly used in a nomadic way. As today these (broadband) services do not necessarily require full mobility, mini cells can already be deployed in the short term providing improved performance and macro network off-load.

[1] Please note that the figures provided in Table 1 are indicative for the performance of the mentioned radio technologies.

Table 1. Overview of wireless technologies

	Peak Downlink	Typical dowload data rate	Frequency allocation	Channel bandwidth	Number of RF Channels	Radio Technology	Typical range outdoor / indoor	Mobility support
802.11a	54 Mbit/s	25 Mbit/s	various bands around 5 GHz	20 MHz	8	OFDM	40-60 m (8) / 25 m	no, (12)
802.11b	11 Mbit/s	6.5 Mbit/s	2.4-2.497 GHz (ISM)	23 MHz	13	DSSS	50-80 m (9) / 35 m	no, (12)
802.11g	54 Mbit/s	25 Mbit/s	2.4-2.497 GHz (ISM)	(3)	(3)	(3)	50-80 m (8) / 25 m	no, (12)
802.11n	600 Mbit/s	100-200 Mbit/s	2.4 and 5 GHz	40 MHz	13	OFDM	75-125 m / 50 m	no, (12)
802.16d	75 Mbit/s	30 Mbit/s	2-11 GHz 10-66 GHz	1.25-20 MHz (4)	(4)	(7)	1-30 km / 50 m	no, (12)
802.16e	75 Mbit/s	10 Mbit/s	2-11 GHz 10-66 GHz	1.25-20 MHz (4)	(4)	(7)	1-5 km / 50 m	(13)
EDGE	0.5 Mbit/s (2)	0.1-0.2 Mbit/s	900 and 1800 MHz	200 kHz	(5)	TDMA with FDD	1-5 km (10) / 100 m	yes
Enhanced EDGE	1.3 Mbit/s (2)	0.3-0.4 Mbit/s	900 and 1800 MHz	200 kHz	(5)	TDMA with FDD	1-5 km (10) / 100 m	yes
UMTS (1)	2 Mbit/s	0.4 Mbit/s	1920-1980 MHz 2110-2170 MHz	5 MHz	(6)	W-CDMA with FDD	300 m-5 km (11) / 50 m	yes
HSDPA	14.4 Mbit/s	3-4 Mbit/s	1920-1980 MHz 2110-2170 MHz	5 MHz	(6)	W-CDMA with FDD	300 m-5 km (11) / 50 m	yes
HSPA+	28.8 Mbit/s	10-14 Mbit/s	1920-1980 MHz 2110-2170 MHz	5 MHz	(6)	W-CDMA/ MIMO/ FDD	300 m-5 km / 50 m	yes
LTE (HSOPA)	100 Mbit/s	30-40 Mbit/s	2.6 GHZ	1.25-20 MHz	(6)	OFDMA/SC-FDMA/ MIMO/FDD and TDD	300 m-5 km / 50 m	yes

Notes

(1) From different variants of UMTS and its successors, here only the European versions are considered.

(2) This is the maximum data rate using eight time-slots and Coding Scheme 4 (CS-4).

(3) For data rates 1, 2, 5.5 and 11 Mbit/s the same channel spacing, bandwidth and modulation is used as in IEEE 802.11b (for backwards compatibility). Other supported bit rates use OFDM.

(4) IEEE 802.16 is designed for a wide range of licensed and license-exempt frequencies with a flexible bandwidth allocation to accommodate easier cell planning throughout the world.

(5) Same as in GSM.

(6) Number of frequency bands depends on operator's licence.

(7) IEEE 802.16 physical layer supports three access technologies: 1. Single Carrier Modulation (CS), 2. OFDM in combination with TDMA, and 3. OFDMA. OFDM and OFDMA are mainly purposed for none 'line of sight' operation.

(8) Lower bound corresponds to 54 Mbit/s data rate, and upper bound corresponds to 11 Mbit/s data rate.

(9) Lower bound corresponds to 11 Mbit/s data rate, and upper bound corresponds to 2 Mbit/s data rate.

(10) With Coding Scheme 1 (CS-1), the coverage radius of GSM voice and GPRS/EDGE data is the same, with CS-2, CS-3, and CS-4 the coverage radius reduces. Typical range in this table is for urban areas. Theoretically the maximum range could be as much as 20 km.

(11) Typical range in this table is for urban areas. Theoretically the maximum range could be as much as 30 km.

(12) Movement within a cell is possible. Technology itself does not support handover.

(13) Technology itself does not support handover. Mobile WiMAX implementations should include mobility.

Acronyms

DSSS	Direct Sequence Spread Spectrum	OFDM	Orthogonal Frequency Division Multiplexing
EDGE	Enhanced Data rates for GSM Evolution	OFDMA	Orthogonal Frequency Division Multiple Access
FDD	Frequency Division Duplex	SC-FDMA	Single Carrier Frequency Division Multiple Access
HSPA	High-Speed Packet Access	TDD	Time Division Duplex
HSDPA	High-Speed Downlink Packet Access	TDMA	Time Division Multiple Access
HSOPA	High-Speed OFDM Packet Access	UMTS	Universal Mobile Telecommunications System
ISM	Industrial, Scientific and Medical bands	W-CDMA	Wideband Code Division Multiple Access
LTE	Long Term Evolution	Wi-Fi	Wireless-Fidelity
MIMO	Multiple-Input Multiple-Output	WiMAX	Worldwide Interoperability for Microwave Access

Complementary Access Planning Framework

This section covers a framework for a complementary access planning tool. As all access means (electricity, water, gas, telecom) are to be regularly renewed, an integral planning tool (e.g., for digging activities) could be envisaged on a trans-sectoral level [3].

The tool described below enables the telco's planning personnel to perform the provisioning process of fixed, mobile and wireless technologies, leading to an optimally balanced complementary access network. Figure 4 shows the framework's building blocks.

1. The ***blue technology part*** on the left is technology related and discriminates outdoor, indoor and fixed deployment. The green modules inside specify and detail the technological properties depending on their deployment. Modules can easily be added, changed or left unused.
2. The ***orange operator part*** comprises the operator's specific input, being the current installed base, the current traffic, the forecast and the (negotiated) equipment costs.
3. The ***yellow geographic information system part*** provides the demographic and geographic data maps.
4. The ***pink dimensioning part*** processes the input from 1–3. Inside the dimensioning part of the planning tool a traffic density map is created where every pixel geographically represents the local traffic intensity. The green modules represent the constraints given by the operator, being bandwidth per end user, coverage, blocking rates and the operator's technology selection.
5. The ***purple output part*** represents the calculated technology mix and a derived geographic visualisation of the position and capacity of the sites. Completed with the calculated investments (CAPEX) and recurring costs (OPEX), a complementary access scenario for a selected area is established. Thus, several scenarios can be simulated, varying the operator's preferences and constraints. The outcome of each scenario with different mixes of radio and fixed technologies can be compared. Doing so, the tool can give a more in-depth financial and operational insight.

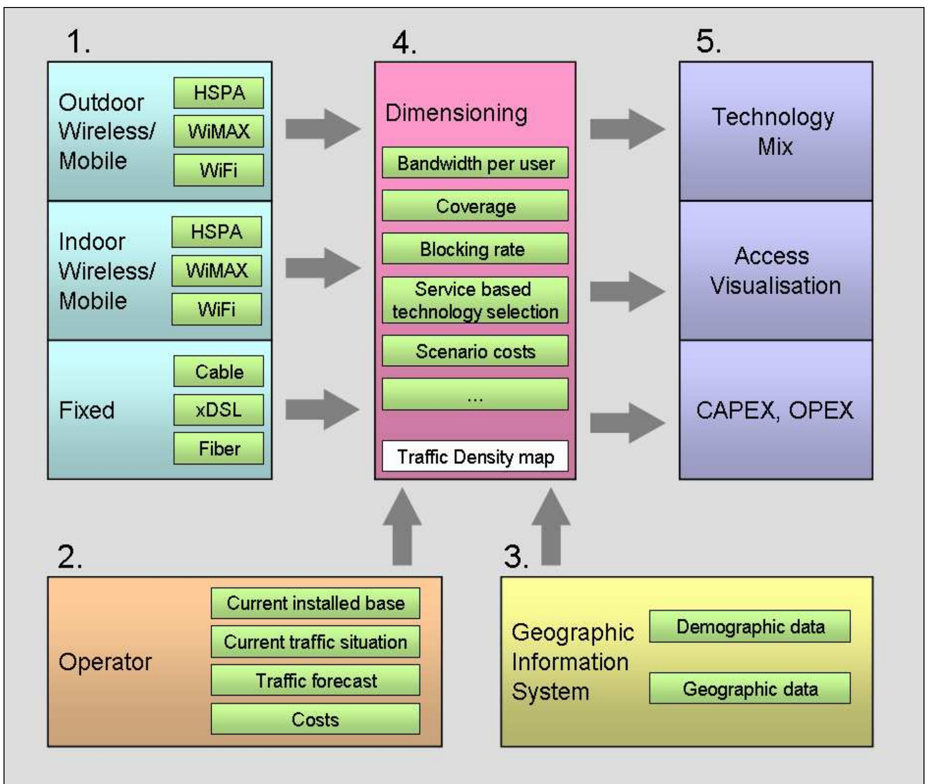

Fig. 4. Framework for a complementary access planning tool.

HSDPA Offload Case Study

Currently, the Netherlands host 16.4 million inhabitants, living in 7.2 million households on a surface of only 38.000 km^2. An overview of the population density distribution [4] is given in Fig. 5. It clearly shows the demographic status quo. e.g., 94% of the inhabitants occupy 19% of the national area[2]. Ten million people live within the so called “Randstad”, an urban area demarcated by Amsterdam, Utrecht, Rotterdam and The Hague.

As average distances are small and the regulatory climate is friendly towards new entrants, the attractiveness of the Dutch playing field resulted in a prime position for this country on the global telecom ranking list of competitiveness and broadband market penetration. Summarizing some facts, in early 2007 broadband access was installed in 69% of all households [5]. In 2006, the number of mobile subscriptions (SIM cards) exceeded the number of people. Increasing WiFi deployment and its use of unmanaged spectrum could lead to interference problems in urban areas in the mid term. In The Hague, for example, an area exists where 27.000 people live in one km^2.

Given the trend of increasing mobile and wireless bandwidth use, macro network capacity provisioning should closely follow at the same pace and moreover, seems to evoke a necessity for radio offload. A uniform macro network could locally be heavily stressed or have to be largely over-dimensioned. A balanced solution seems to be more appropriate. Unused and new fixed broadband access capacity could be increasingly deployed for transferring both mobile and wireless traffic. In the Netherlands the cable, xDSL and FttH installed base is expected to grow steadily (2009 forecast indicates the FttH penetration is to exceed 15%). This is where micro, pico and femto cells come into play, being attached to fibre, xDSL and cable access means. In this perspective an offload case study was performed.

The ongoing growth of wireless/ mobile bandwidth use demands a similar

[2] CBS Demographics 2006.

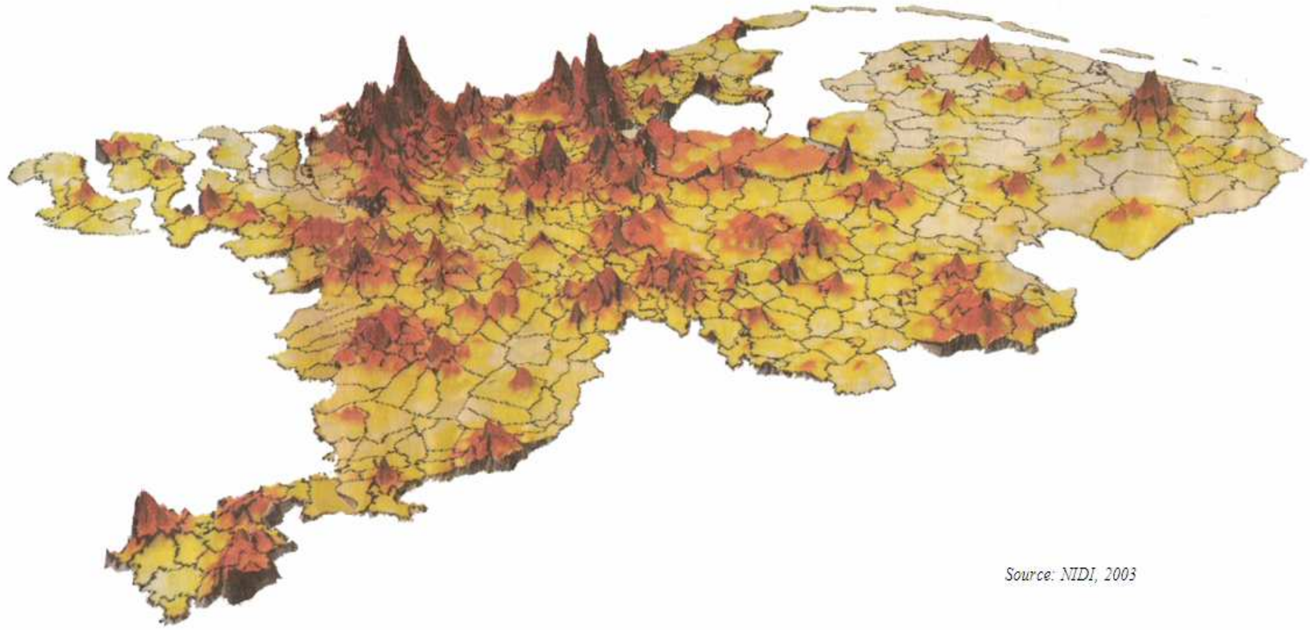

Fig. 5. Population density distribution 2003.

increase in capacity of the network. A couple of methods are available to increase the capacity for the existing macro network. For the radio planning the methods in preferable order are: increase the number of carriers per site, if the operator spectrum license allows for this. The second way is to increase the number of sectors on the site. Nowadays three sectors are standard, but four or six sectors and even more are available in the near future. If both methods are fully exploited, one can turn to building extra sites to increase the capacity. However, this brings up two issues: cost efficiency and above all regulation. In the Netherlands for example, already 70 out of 500 municipalities strongly discourage deployment of new UMTS outdoor sites. Keeping these constraints in mind, three future HSDPA scenarios were simulated. Figure 6a shows the geographical map of a representative suburban area. To predict the traffic volume for this area in 2009, a novel traffic grid was developed, depicted in Fig. 6b. A traffic grid is a geographical map showing the local traffic intensity averaged over a certain period of time. The data is gathered from traffic analysis of the current macro network in operation. While today UMTS and HSDPA are not yet widely used, a GSM traffic grid was scaled up following a traffic forecast for 2009. The GSM grid was modified for a next generation situation by subtracting the traffic generated at highways, because it is possible to call hands free, but it is certainly less easy to use broadband services while driving. Three scenarios have been simulated aiming to have full coverage of the selected area offering a minimal user throughput guarantee.

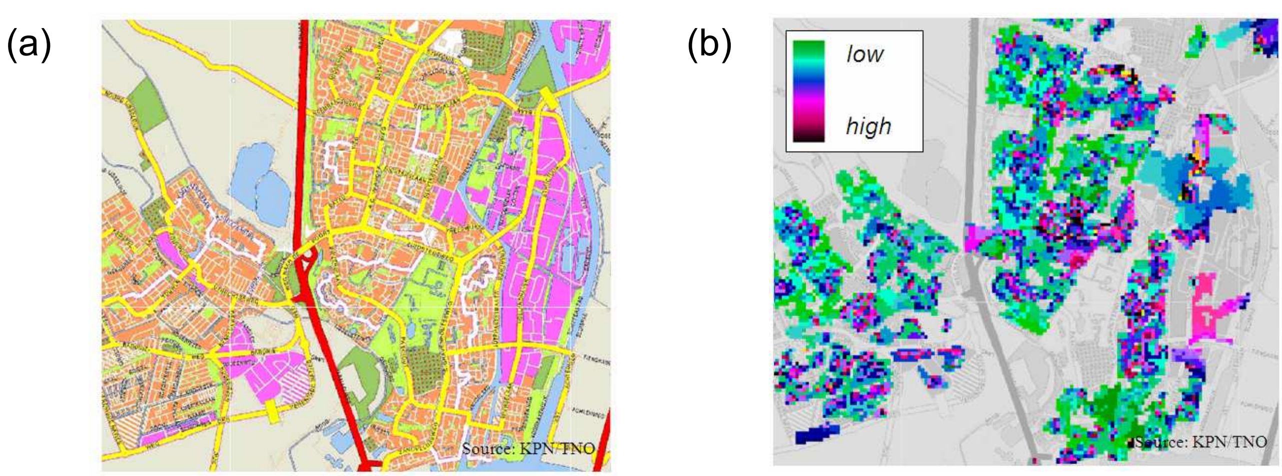

Fig. 6. (a) Map of simulated area. (b) Traffic grid.

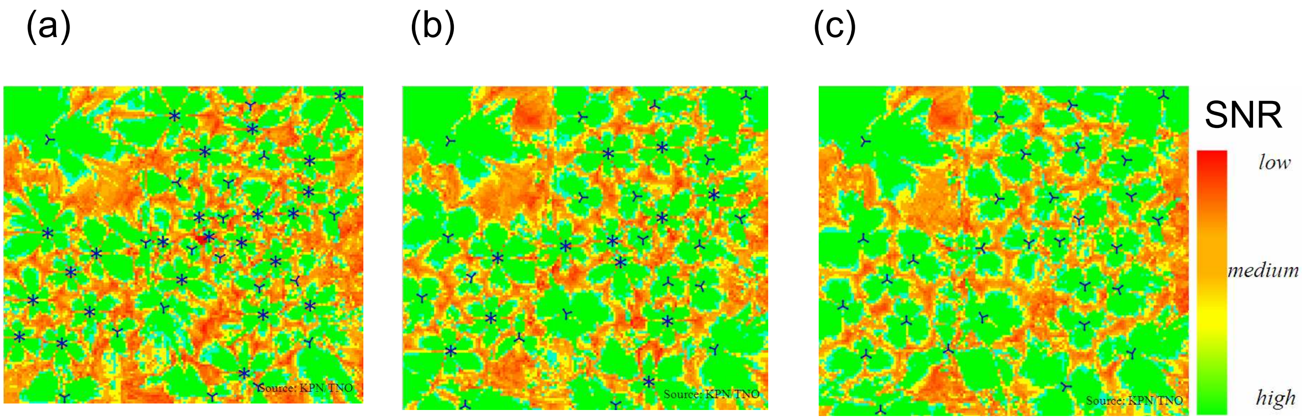

Fig. 7. (a) No offload. (b) 40% static offload. (c) 40% static + 40% nomadic offload.

1. Scenario A (Fig. 7a) is a scenario where the macro network scales up to meet the forecast, resulting in the need of the deployment of more than twice as many sites. Most of the sites have 6-sector antennas and use the maximum number of available carriers.
2. In scenario B (Fig. 7b) we assume a 40% static traffic offload (inside and around the user's home). Compared to scenario A not only fewer sites are required in general but the number of six-sector sites is reduced significantly as well. The net present value of the cost reduction compared to scenario A is about 20%.
3. In scenario C (Fig. 7c) we assumed an extra 40% offload (total 80%), when users open their mini cells to allow nomadic use. Three-sector sites suffice and again much less sites need to be deployed, resulting in a cost reduction of approximately 40% (NPV) compared to scenario A.

We conclude from the case study that when no off-load solution is available an unfavourable dense macro network is required. Next to the high costs of such a network are considerations that the high bit-rate areas at the centre of a radio cell are smaller, due to a larger surface with lower Signal to Noise Ratio (SNR). Indoor mini cells could off-load macro cells and improve user bitrates indoor, as well as outdoor. However, a dense macro network may still be required for capacity reasons in the long term.

Roadmap

Departing from today's fragmented infrastructure situation, the first milestone on the roadmap towards personalised liquid bandwidth is the mini cell, as illustrated in Fig. 8. Being regularly upgraded, mini cell capability sets could gradually incorporate functionality like: SIM, Node-B, RNC, GGSN, and SGSN. After adding mini cells to the macro plane, and having gained some initial footprint, a necessary second milestone ought to be reached: the set up of a complementary access planning and provisioning process. Imagine having established this process, the operational and commercial portfolio is ready for a next stage in real time service offering.

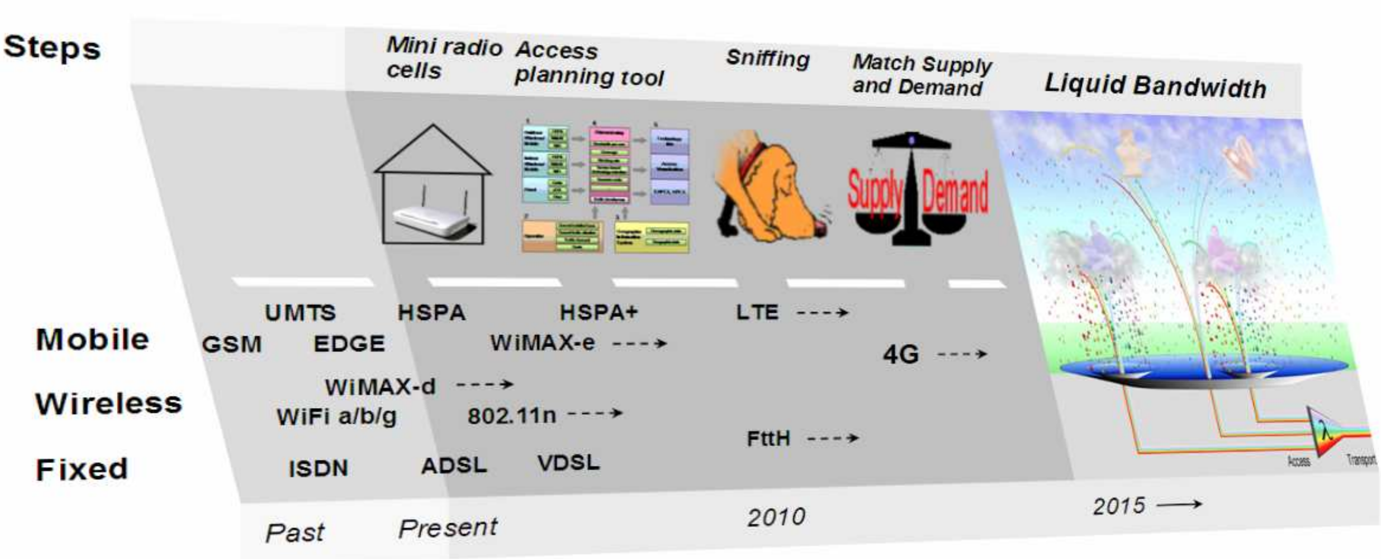

Fig. 8. Roadmap to personalised liquid bandwidth.

Communication devices inside the customer's personal area network can continuously interact via the complementary access network with the service plane and even commercial outlets, recognising the identity of the device and its owner. Handovers can be performed during communication sessions. When moving, connectivity offers can reach these devices. As many providers and operators are trying to survive in our current Anglo-Saxon climate, commercial interests and tariff issues will initially slow down this general breakthrough of real time access sniffing.

Later on as the market adopts these novel telecom oriented concepts, the transactional functionality could be extended to sniffing the right offer. Negotiating and real-time bridging supply and demand without the use of banknotes and coins can be performed instantaneously using trusted personal ICT means. Thus, sniffing [6] might evolve from: 1) sniffing the right access, to 2) sniffing the right offer, to 3) sniffing the right people for any potential transaction or fruitful contact [7]. In this still imaginary stage where optical connectivity will be deeply integrated into our networks, society will have reached a personal liquid bandwidth stage.

Conclusions

The telecom infrastructure will face fundamental change due to three major trends: firstly increasing demand for personalised high QoS services, secondly the tendency to enjoy services wirelessly, and thirdly an ever growing bandwidth need.

Next Generation telecom properties derived from these trends comprise personalisation, openness, mobility support, broadband capacity and complementary fixed/wireless access.

We conclude that the rise of the mini cell is inevitable, combining these future properties with the following facts:

- mini cells can realise macro cell functionality indoor as well, improving total coverage and improving bit rates indoor, as well as outdoor;
- fixed indoor capacity can transfer additional mobile/wireless traffic at lower integral cost;
- lower energy consumption and lower electromagnetic radiation are generally encouraged;
- municipalities actively discourage deploying new outdoor macro site radio antennas.

Bandwidth represents value, irrespective of the business model. Generally wireless bandwidth is more expensive than fixed bandwidth. From an operator perspective mini cells (within a complementary access context), improve the overall infrastructure performance, because mini cells can offload the macro network without loss of perceived quality.

Complementary access planning gives (financial) insight and geographically optimizes cost efficiency combining heterogeneous wired and wireless access technologies.

As ICT services, devices and broadband networks are to become personal, reliable and trusted, these new requirements have to be met. Doing so, a new societal stage lies within reach. Personal networks could become the prime transaction instruments, and not just for finding the appropriate access. In mini cell environments SIM technology again seems the best in class authentication technology to meet trust and security requirements for any type of communication service.

The expected mechanism offering the end-user the possibility to sniff the right access, could evolve into functionality sniffing the right offer, and even sniffing the right B-party for any transaction over any distance, almost instantaneously matching supply and demand.

Assuming average bandwidth need keeps on increasing according to Moore's law from today's 4 Mb/s fixed lines, towards a 100 Mb/s in 2015, a future image starts to unfold where a Lambda per end user becomes feasible. Still hidden, far ahead in time a Lambda per session might be the case. Anyway, we believe these kind of connections and sessions require optical circuit-switched networks.

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