Small-cell Challenges for Mobile Networks' Wireless Backhaul

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***Abstract*- Higher data rates in mobile networks imply smaller distances from base-station to mobile user. Number of network elements increase while the cost pressure is high. For economical purposes wireless connections are preferred in mobile backhaul infrastructure in several cases and millimeter-wave bands are the only option to carry the needed multi-gigabit capacity. New kind of network topologies are needed. The author will present this challenge from mobile networks' wireless backhaul point of view, bring out possible solutions and the consequences for wireless technology.**

I. Introduction

Mobile communication networks are based on cellular technology where mobile hand-set (i.e. user equipment, UE) users are connected to a base station (BTS). BTSs are the access points for the users to the Radio Access Network (RAN) that provides transmission path to the services located in Core or Internet network. The transmission connection from a BTS to the nearest controller of RAN is called Mobile Backhaul (MBH).

Requirements for MBH are growing due to increased data speeds and cost pressure. UMTS Forum predicts that total annual traffic in mobile networks globally will reach 127 Exabytes volume in 2020 that is 33-times higher compared to 2010 figure [1]. All this traffic is to be carried over a backhaul network. Despite the fact that fast wire line technologies are widely available operators who build RANs still prefer wireless means to connect BTSs. Over 55% of all MBH physical connections worldwide nowadays have been implemented by microwave radio link and 63% of all newly installed MBH connections in 2014 are estimated to be wireless, i.e. microwave or millimeter wave links. [2]

II. Challenges

A. Increasing data rates

Mobile networks data rates during the 2nd (GSM) and 3rd generation (WCDMA) have been quite moderate. Now when 3rd Generation Partnership Project's (3GPP) standards evolved to HSPA and LTE maximum mobile terminal user data rates are growing to 75 Mbit/s in uplink and 300 Mbit/s in downlink. The 3GPP Long-Term Evolution Advanced (LTE-A) is an example how ITU International Mobile Telecommunications-Advanced (IMT-Advanced) systems will be implemented. [3]. When entering to LTE-A/IMT-A era the target user data rate for has been set as high as 1 Gbit/s. If this is assumed to be the maximum data rate of one BTS (or eNB) cell, one BTS manages 3 cells and data aggregation ratio of 80% is assumed, the backhaul peak rate requirement for a BTS is 2.4 Gbit/s.

An other challenge is to keep data round-trip time from mobile handset to the network services at acceptable level. Tendency to use time-division duplex and packet-based transport systems tends to increase latency.

B. Radio frequencies

Radio frequencies are a scarce natural resource and have clear technology dependence. Microwave bands mainly used in existing terrestrial fixed wireless applications are between 7 – 39 GHz. There is 17.95 GHz bandwidth allocated for fixed service between 10 – 40 GHz [4]. Some microwave bands start to be pretty congested in certain areas like 15 GHz in Asian countryside and 23 GHz in western urban areas.

Majority of radio channels in currently allocated frequency bands have bandwidth of 7...28 MHz. Taking into account practical implementation trade-offs between cost, complexity and performance this is too narrow for high capacity applications of LTE and LTE-A era. Advanced modulation and radio techniques at the current technology allow link spectral efficiency of about 8 bits/s/Hz.

Lower MW frequencies (below about 15 GHz) are beneficial because they enable long hops and obstructed path connections. However they may not be optimum for dense network with short hops. Strict line-of-sight requirement for high microwave and millimeter wave frequencies increases the complexity of network planning. Also atmospheric gas and rain attenuation decreases the hop-length or availability.

Although frequency allocations for fixed usage are available there is often variation in regulation between countries and regions. This complicates the design of global products and sets flexibility requirement for technologies used in equipment.

C. Cell size

Tendency for high data rate, small physical size and long operating time in mobile hand-sets squeeze the UE-BTS –link budget. On network infrastructure side energy consumption, size and cost/complexity –requirements in RF and base-band functions in similar way drive smaller cell sizes in mobile

networks. This tendency leads to higher BTS density, shorter MBH links between network nodes and need for higher number of links per unit area (km^2). At the same time when number of MBH and RAN equipment density increases the operators revenue for selling mobile services are not always increasing in the same pace.

D. Equipment size

Telecommunication infrastructure equipment have not any more a privilege to be located in special premises, but are more often located in public places. Small size and esthetic design are important features for infrastructure equipment and enable them to spread in vicinity of people.

E. Energy consumption

It is estimated that globally BTSs produce 30 million tons of carbon dioxide annually. This is more than all other mobile network equipment together including mobile terminals [NSN]. In many developing countries where mobile communication use is growing not only the environmental considerations but also energy availability is a problem. Low power consumption is then a mandatory requirement.

Relatively high-power BTS amplifiers are becoming more and more energy-efficient thanks to techniques like active biasing, pre-distortion and envelope tracking. Also the absolute transmitter power is decreasing due to smaller cell sizes. If no innovation is done to reduce also backhauling radios' energy consumption, MBH's relative portion of consumption will grow.

F. Cost

As can be seen from the market figures and nature of industry telecommunications have become commodity. Similar cost requirements apply to infrastructure equipment as to consumer products. The equipment cost only, however is not the only target for application design. Total cost of ownership (TCO) for operator is typically calculated as the sum of capital expenses, implementation expenses and operating expenses over five years for the whole MBH service. When the cost of equipment degreases its effect to TCO diminishes.

III. Consequences

In this chapter possible solutions and further proposals are made to tackle with previously mentioned challenges.

A. Modularity

When considering the internal architecture of a radio equipment there are lots of similar functions or building blocks with slightly different parameters. These can be for example frequency band, bit rate and antenna. There are benefits for hardware development and manufacturing, software development and life-cycle management if similarities are found and utilized. Idea of modular design tries to develop interchangeable platforms and modules.

Because of strong frequency dependency typical for radio frequency components benefits of modular design may be limited. Developing wide-bandwidth circuits or developing circuits that center frequency can be changed during operation in a wide promote this target.

B. Higher frequencies

From frequency standardization point of view frequencies are well available for terrestrial fixed wireless usage. Between 40 – 100 GHz bandwidth allocated for fixed service is 26.62 GHz [4]. Specifically for High Density Fixed Service (HDFS) usage between 31 – 66 GHz is identified band of 14.02 GHz. Channel widths for HDFS are typically wider than in lower bands. Regulation is available in some countries for new bands while in some countries preparation is ongoing. Globally harmonious ways to use for these new bands would help developing products for global markets. Technology to utilize these bands is now needed.

C. Circuit systems

New circuit techniques and materials are needed to achieve many of the targets drafted here. For example fixed millimeter wave radios require higher transmitter power levels than handheld communication equipment or other very short range devices. Because fixed links are part of communications infrastructure the failure rate of electronic components must be low. Typical MTBF figures nowadays are 50...100 years for an equipment.

Intuitively high degree of integration enables smaller equipment. It also provides potential for other benefits, like power saving through lower losses, smaller material and production costs and higher reliability. In some cases it may be contradictory with requirement of modularity.

D. Antenna

Typical fixed wireless point-to-point applications and standardization as well favor highly directional antennas. High directivity helps to achieve high system spectral efficiency ($bit/s/Hz/km^2$) and make dense systems. Parabolic antennas are widely used, but other constructions like lens or flat-panel (array) antenna may better fulfill product design targets.

From system point of view wider antenna beams have also benefits. Wider antenna beam would make antenna alignment easier and allow installations to swinging poles. One solution to combine multiple requirements is to use electrically steering antenna with automatic steering algorithm. Figure 1 shows how an area of a sector antenna can be covered by discrete narrow antenna beams.

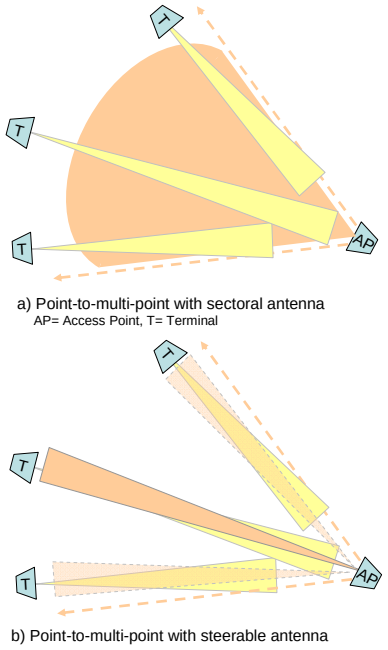

Figure 1. Area coverage for fixed wireless connection a) with sector and b) with beam-steering antenna.

E. Mixed network topologies

To tackle with previously mentioned challenges fixed wireless networks for mobile networks backhauling require also re-thinking of network topology. Optimized networks combine point-to-point, point-to-multipoint and mesh topologies, Fig.2.

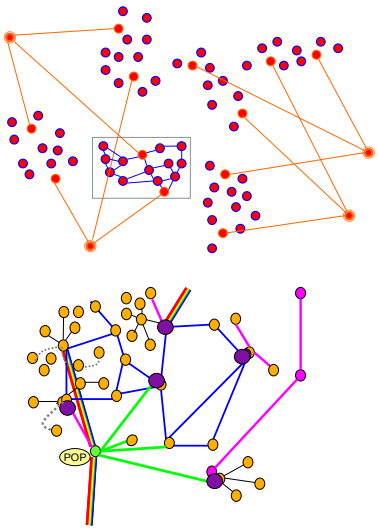

Figure 2. Example of mobile network backhaul topologies in rural (top) and in urban (bottom) environment.

In the upper picture there is an example of rural MBH network where access-points with larger capacity, possibly connected to a fiber optical network, provide capacity to large area with sparsely populated villages. Villages are connected to each other by a mesh network. Redundant connections to each cloud of villages increase the availability of service. On the right there is a high capacity urban network. Some of the hops are line-of-sigh operating over the rooftops of a city. Majority of the BTSs however are located on the street-level to provide best coverage for mobile UEs. Path to these sites may be near- or non-line-of-sight due to obstacles. Some of the BTSs may be located in-house.

Wireless equipment of different frequency bands and technologies are needed in parallel, even integrated into same network nodes. Trunk of the network requires equipment with larger bandwidth, while last branches can use low capacity non-line-of-sight links.

Compared to traditional sole point-to-point wireless connections mixed network with partial mesh topologies enable data traffic load and capacity balancing. They also increase network availability by providing redundancy [5].

Fig.3 depicts network full availability (i.e. all nodes available) as a function of allowable down time (DT) for different network topologies and network sizes (i.e. number of network elements). Hardware mean time to failure (MTTF) for network elements is assumed 40 years, and rain induced availability target for a single hop is 99.99% of time. Differences are negligible between European and Far East rain zones, so only European case is shown

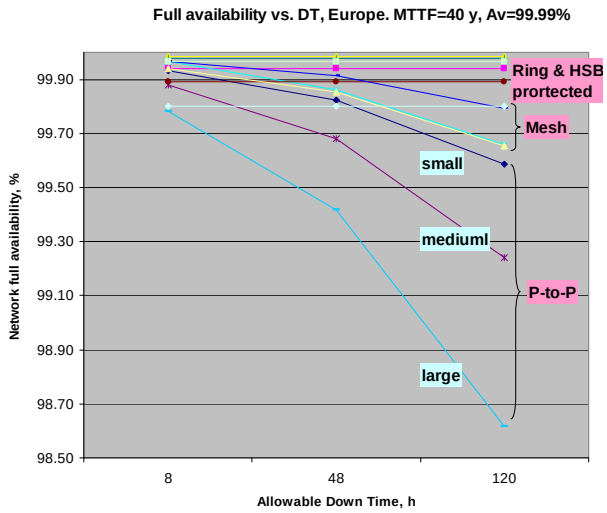

Figure 3. Total availability of a wireless network as a function of repair time for different network topologies and sizes.

Due to strong HW redundancy down time variation practically does not affect to protected P-to-P Ring and P-toP-hot-standby (HSB) topologies. In the figure they are almost

vertical lines. If we let node down time to grow (i.e. increase the repairing time), availability in P-to-P tree topologies collapses, even faster when network size increases. Mesh topology degrades only moderately and effect of network size is not so large. For example at eight hour DT level full availability difference between large mesh and P-to-P networks is 0.16%-units while at 120 hour level difference is 1.1%-units that corresponds 4 days availability difference per year.

IV. Conclusion

End-users of information services, like Internet, prefer wireless and mobility. Wireless seems to be the preferred method also in mobile base stations' 1st and 2nd mile backhauling. Requirement of higher data rates and international frequency allocations foster the use of millimeter wave bands for wireless MBH. Higher frequency implies smaller antenna size and also matches the idea of smaller cellular network cell size. Technology have been studied but it is not yet mature for low-cost 60...100 GHz mass products for fixed wireless. More research on smart antennas for mobile backhauling applications are needed. System level analysis of applications are needed to understand the key design parameters and their importance for millimeter wave technology that enable future applications.

References

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