Using Distributed Antenna Systems to Extend WLAN Coverage

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Abstract—**Many of the WLAN hotspots are significant in size and achieving good coverage may be challenging. The current standard for providing coverage is to distribute individual WLAN access points in the target area. Due to the fact that the in-building environment has many challenges, such as walls and elevators, the number of access points needed by using this method may become significant.**

There are several benefits of implementing the WLAN over a distributed antenna system (DAS). For example, the WLAN coverage and capacity can be improved and the coverage area can be shaped in a more efficient way. Furthermore, the integration of WLAN with the existing cellular DAS will reduce hardware and related installation cost and services dramatically compared to two stand-alone networks.

I. Introduction

THE WLAN hotspot market is growing fast and the variety of hotspots targeted for implementation is considerable. Many of the hotspots targeted are significant in size and achieving good coverage may be challenging. The current standard for providing coverage is to distribute individual WLAN access points (APs) in the target area. The number of APs needed by using this method may become significant. For example, up to 5000 APs can be required to provide coverage in a facility such as an airport [1].

A Distributed Antenna System (DAS) is the infrastructure used to distribute radio signals from one or more radio base stations and radio access points to any number of antennas located throughout the wanted coverage area, e.g. a building. The coverage area may be covered by one or more cells, where each cell is typically served by any number of antennas multi-casting the same signal.

The DAS is the most effective and most flexible method to provide coverage inside a building. A DAS allows better control of the service area borders of the in-building system. At the same time, it provides high-quality coverage and low interference compared with using base stations and access points with integrated antennas. In addition, the DAS provides better radio trunking efficiency by allowing larger portions of the building to be served by a single cell or access point. This makes the frequency planning easier since less channels are needed to support the in-building traffic, which results in higher capacity with less interference.

The structure of this paper is the following. First, in Chapter II the usage of DAS to extend WLAN coverage is motivated in more detail. Then, in Chapter III the various DAS alternatives are introduced, and in Chapter IV the WLAN DAS deployment is discussed. In Chapter V some recent research issues are listed, and finally, in Chapter VI some conclusions are drawn.

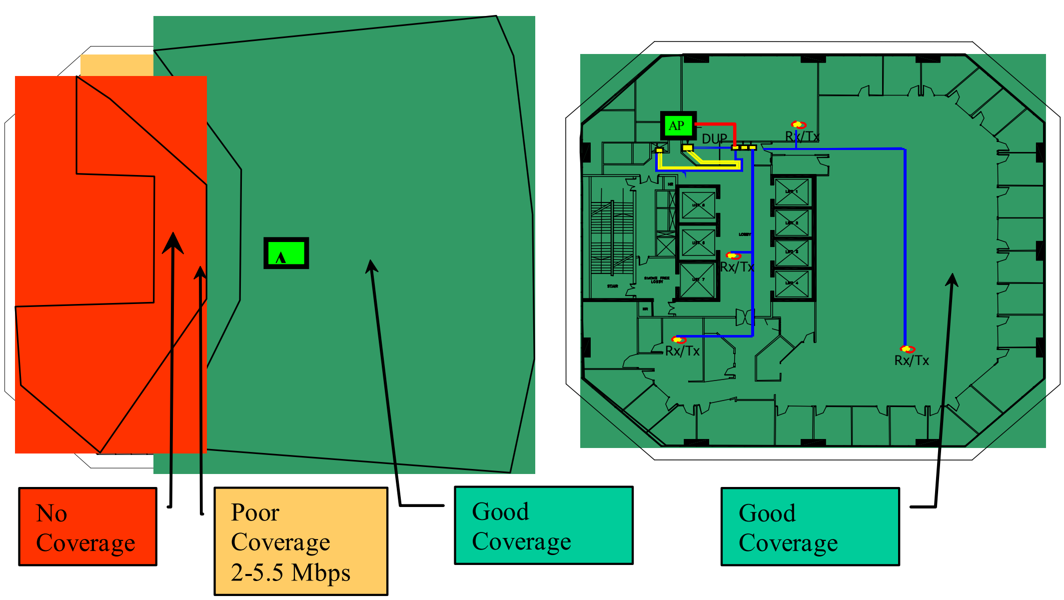

Fig. 1. With DAS the in-building coverage of an AP can be improved.

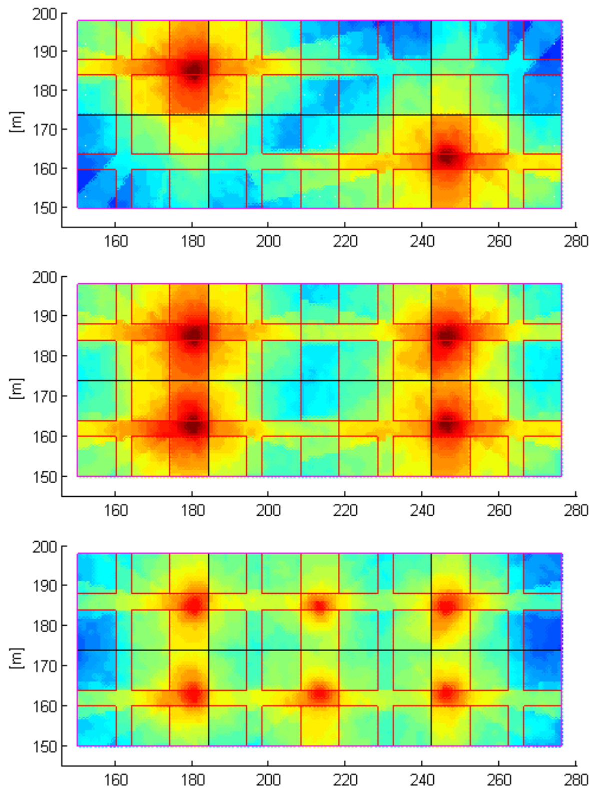

Fig. 2. Predicted WLAN signal strength with a) two APs (EIRP = 20 dBm), b) four APs (EIRP = 20 dBm), and c) two APs, each one connected to a DAS with three antennas (EIRP = 10 dBm per antenna).

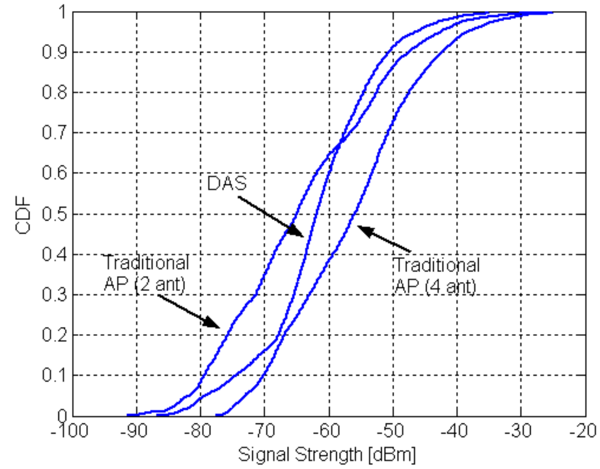

Fig. 3. Distribution of the predicted WLAN signal strength levels from Fig. 2.

II. Motivation: Why WLAN and DAS?

A. Improved Coverage and Capacity

The theoretical coverage or 'footprint' from a "stand alone" AP has a radius of 100 m. Unfortunately, this is far from the actual performance inside a building. The in-building environment has many challenges such as walls, elevators, and fire shutters that, in most cases, effectively block the signals. However, if deploying a new, or using an existing cellular DAS, it is possible to leverage from the careful engineering that has been done to identify the optimal location of the antenna points, see Fig 1 [1].

In case of WLAN the achievable link data rate depends typically on the distance between the user and the access point: the larger distance (i.e. larger path loss), the lower link data rate. However, the achievable data rate for users located at the same distance from the access point varies with different spatial locations as well. This is because even though these users may experience same distance-dependent path loss, the shadow fading varies due to different blocking objects, especially for in-building environments.

With the use of CSMA/CA protocol, low rate users affect the throughput and delay performance of the whole system significantly. In fact, if a user with low link data rate is going to download a large file, it will need a greater number of time slots. Once this user has contended for the use of the channel, others have to wait for a long time to gain subsequent access themselves. Therefore, there is a need to increase the link data rate while maintaining the transmission/reception performance (e.g. bit error rate or symbol error rate), for users located everywhere within the cell.

In order to provide high link data rate for all users within the service area, existing technology has to utilize multiple traditional access points, each of which covers a limited area. Since the number of non-overlapping WLAN frequency carriers is quite limited, a large number of access points may lead to a considerable level of co-channel interference, which reduces the overall system throughput. In addition, the throughput increment is achieved at the cost of increasing the overall rollout cost linearly with the number of additional access points, as compared to one traditional access point.

Thus, with the use of DAS, the same, or improved area coverage can be offered with a smaller number of access points, as compared with a deployment with traditional access points.

A simple example is given in Fig. 2. There, the first figure shows the predicted WLAN signal strength within a fictitious floor in case of two access points, assuming EIRP equal to 20 dBm (100 mW) per AP. In the second figure, the same area is covered with four access points. Finally, in the third figure, a passive DAS with two APs and six antennas (three antennas per AP) is assumed. There, the EIRP per antenna is 10 dBm. In the light blue nodes the signal strength is approximately -70 dBm, while in dark blue areas the signal strength is roughly -85…-80 dBm. The signal strength distributions are summarized in Fig. 3. As can be noticed, the deployment with a passive DAS offers a better coverage than the traditional deployment using two APs, but not as good coverage than with four APs.

B. Coverage Confined into Building

Uncontrolled spillage is a common side effect from "stand alone" implementations. This is particularly sensitive if the installation is serving a corporate environment, where data security is a priority. By using a DAS, better control of the footprint can be obtained, which makes it possible to better constrain the signals to within the building.

This is also demonstrated in Fig. 1 and Fig. 2. In case of traditional APs, the signal strength next to the outer wall (inside the building) is around -50…-45 dBm (Fig. 2). Assuming an outer wall loss of 20 dB (considerably less in case of a window), the WLAN signal can be clearly received from outside the building. With a DAS, the EIRP is 10 dB lower, which also reduces the WLAN leakage accordingly.

C. *Other Reasons*

When implementing WLAN hotspot coverage in a shopping mall, using a "stand alone" method, the service provider has to negotiate with each individual tenant, controlling the space in which he wants to install a AP. This is a highly time consuming and expensive process. By implementing WLAN coverage using a DAS, a service provider need only conduct one single negotiation with the building owner. Once his/her approval has been obtained, it is possible to WLAN-enable the whole building [1].

III. Introduction to Distributed Antenna Systems

The distributed antenna systems for in-building applications can be divided into three categories:

1. Distributed antennas using a coaxial feeder network.
2. Radiating cable.
3. Distributed antenna using a fiber-optical feeder network.

The two first ones are referred also as passive antenna systems, while the last one is typically an active antenna system. A fiber-optical DAS enables the use of low power radio base station (RBS), whereas a coaxial solution often requires a high power RBS. It is possible, and in some cases also the optimum solution to combine a coaxial system (near area coverage) with a fiber-optic antenna system (remote area coverage) to be able to cover remote parts of the building. This kind of mixed deployment is often referred as a hybrid antenna network.

Next, the different types of antenna systems are explained in more detail.

A. *Passive Distributed Antenna Systems*

1) *Coaxial Distributed Antenna Network*

Antennas distributed via a coaxial feeder network (passive DAS) is by far the most popular antenna configuration for cellular in-building solutions, and has also the widest range of applications. This is due to some of the attractive features offered by the configuration:

- Low hardware cost
- Flexibility in the design when shaping the coverage area:
  - Power distribution can be controlled by using unequally distributed power splitters.
  - Additional antennas are inexpensive and easy to add on.

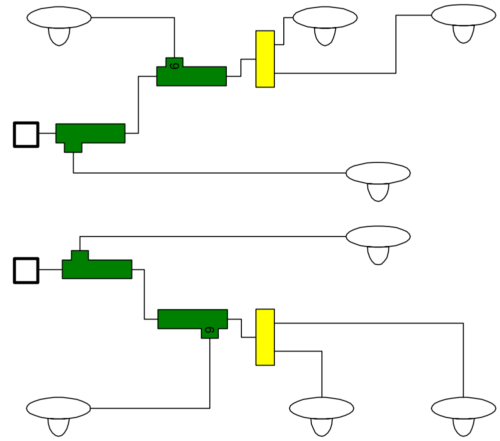

Fig. 4. An example of a passive distribution network including tappers (green nodes) and splitters (yellow nodes).

- Robust and well proven technique: No active devices in the antenna system requiring local power supply and distribution.
- The same system can be used for multi-band and multi-system installations, e.g. GSM900, GSM1800 and WCDMA.
- The installed coaxial distribution network can be easily shared between several operators, which efficiently limits the amount of cabling inside the building resulting in a lower cost of deployment.

The disadvantage of a coaxial distributed antenna network is that in a typical network, the coaxial cabling uses between 20 and 30 dB of the link budget. This results in the need of relatively high power at the base station antenna connector and the resulting cost of the power amplifier. The possibly large cable loss puts also a limit to the WLAN deployment, as pointed out later in this paper.

The typical passive DAS consists of antennas, power splitters and tappers, feeder cables, connectors and jumper cables. An example can be found in Fig. 4. In general, the power splitter is used when the signal is to be divided equally between the output ports. Thus, in case of a 2-way power splitter the signal is split in two paths. This also means that a 2-way splitter has an attenuation of 3 dB, a 3-way splitter has an attenuation of 5 dB, and so forth. A splitter has the same loss both in the uplink and the downlink. The power tappers are used to "tap" a small portion of the signal by dividing the power unequally between the output ports. As an example, a 7 dB type power tapper means that the signal in the "tap" is attenuated 7 dB, while the "forward" part is reduced only 1 dB. The power tapper can also be adjustable. The tapper has the same loss in the uplink and the downlink, both for the tapper and the forward part. Finally, a right combination of splitters and tappers can compensate for feeder loss in a way that almost equal power levels can be achieved for all antennas. By this method, available power can be used where really needed, irrespective of the distance to the base station (or AP) equipment.

Obviously, even though the transmitted power can be balanced by carefully designing the distribution network, the transmission via different antennas will not be synchronized due to the different propagation path lengths both in the cables and in the air. Thus, from the receiver point of view, the delay spread is increased compared to a single antenna scenario. This increase in delay spread should also be taken into account when considering the use of a passive DAS together with WLAN.

2) Radiating Cable System

The radiating cable is a special coaxial cable with slots in the outer conductor, which allows a controlled part of the RF signal to leak out of the cable and also external RF signal to be coupled into the cable. Thus, the cable works as a continuous antenna and can be placed everywhere coverage is needed. The radiation can be considered to be equal in all directions around the cable.

Radiating cable is an alternative to distributed antennas in some applications such as:

- In tunnels, where vehicles can fill up the whole cross section, and where fading due to large obstacles is the main problem.
- In office applications, where there are many partitions with high attenuation making it necessary to have a radiating point in every room.
- In the top floors of high rise buildings, where spillage control is very important.
- Along long, narrow corridors.

Compared to distributed antennas, a deployment based on radiating cables is typically a more expensive alternative, in terms of equipment and installation cost. However, the same antenna near parts (power splitters, connectors etc) can be used for radiating cable installations as well as for distributed antenna systems using coaxial feeder. Therefore it is possible to build in-building solutions with a mix of distributed antennas and radiating cable.

More technical information on radiating cables can be found for example in [2].

B. Active Fiber-Optic DAS

Active fiber-optic systems are typically more expensive than an equivalent passive system, but are more feasible in larger buildings. This is due to the reduction in signal loss provided by using fiber cable. Typical applications for fiber-optical systems include exhibition halls, campuses, underground railway systems, and airports. The system design is very flexible, as capacity and coverage expansions are possible at any time due to the fiber-optical modularity.

In a fiber-optic distribution network, fiber cables are installed throughout the building to the places where the radio/antenna parts need to be installed. These Remote Units (FDAS Remote Unit, FRU) can be low power units connected directly to an antenna, or medium power units connected to a coaxial distributed antenna network. There are both analogue and digital fiber distribution networks. An example of an active (analogue) fiber-optic DAS is shown in Fig. 5 [3].

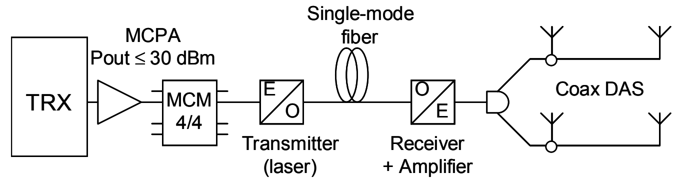

Fig. 5. An example of a RoF distribution network.

In an analogue distribution network, the analogue RF signals are transported directly over the fiber (Radio-over-Fiber, RoF). The analogue fiber-optic links can be divided in two main groups: a) direct modulated links, and b) externally modulated links. In direct modulated links the RF signal is modulating the current passing through the laser diode (LD) and by that modulates the light generated by the LD. The externally modulated links use a DC biased laser generating a CW light, which is coupled through an optical modulator. In general, direct modulated links are used at frequencies below 10 GHz due to smaller size, lower modulation voltage, and smaller cost [4]. More detailed information on the Radio-over-Fiber technology can be found for example on [4] and [5].

The bandwidth of the analogue fiber-optic solutions is normally several GHz making it possible to support the distribution of several systems or operators on the same fiber. However, due to the fact that the optical devices have often a limited dynamic range, it may be quite challenging, or expensive to support different radio technologies on one fiber.

In a digital distribution network, the analogue RF signals are sampled, digitized and transported over the fiber network. At the antenna side the digital signals are converted back and filtered/amplified before going to the antenna. On each digital link, an approximately 30 MHz RF-band can be transmitted, which limits the usage of a digital distribution network compared to the analogue alternative. Furthermore, also the dynamic range is one of the limiting factors.

Due to the use of fiber instead of coaxial cable, the distance between the base station (access point) and the antenna can be up to 20 km. However, for these distances more expensive equipment (lasers) is needed. Cheaper solutions are available for both analogue and digital fiber solutions. Digital solutions using a multi-mode fiber are cheaper, but the maximum distance is limited to approximately 2 km. For short distances, analogue solutions are limited by the noise generated by the laser. Using a cheaper laser the maximum distance is reduced to approximately 3 km, which is however sufficient for most of the typical in-building solutions.

Because the RF amplifiers are located close to the antennas, the output power of these amplifiers can be much less than the output power of a centralized power amplifier. The obvious disadvantage is that a larger number of amplifiers is needed. Furthermore, each one of these FRUs needs to be powered, either remotely or locally. Remote powering requires cabling that can transport both power and RF signals, or a composite cable with separate cables for powering and fiber [6].

Examples of commercial fiber-optic DAS solutions include for example Andrew Britecell® [6] and ModuLite™ from

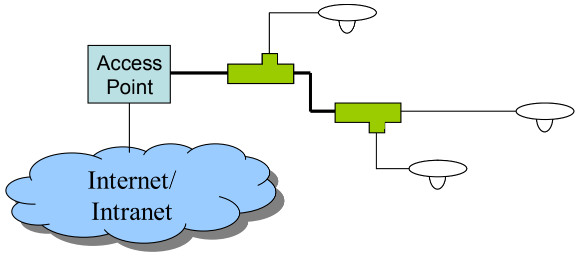

Fig. 6. WLAN access point connected to a passive DAS.

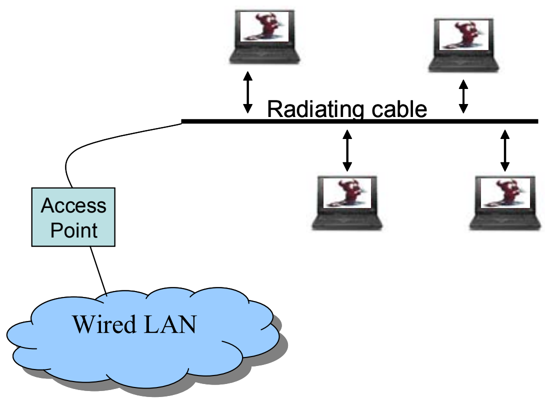

Fig. 7. WLAN access point connected to a radiating cable.

MobileAccess Networks [7, 8].

IV. Connecting WLAN Into a DAS

A. *Stand-Alone WLAN DAS*

In case of a stand-alone WLAN DAS, WLAN is not sharing the DAS with any other radio access technology (RAT). Thus, all the introduced DAS techniques are applicable. However, for the passive coaxial DAS, some limitations should be taken into account. Firstly, due to the limited output power of an AP (100 mW), one AP has enough output power to support approximately 3-4 antenna heads (depending on antenna design), see Fig. 6. Another thing to keep in mind is the delay differences between adjacent antennas. Depending on the installation the delay difference can be somewhere in between 0 – 200 ns (0 – 60 m difference in feeder length), which corresponds to a RMS delay of 0 – 100 ns. A room located between two such antennas will experience a constant time delay spread of a magnitude that the WLAN is not necessarily designed to cope with, see for example [9].

Some of the inherent benefits of radiating cable particularly for containment and uniform coverage, lend themselves well to the architecture required for WLAN networks. LANs are usually arranged in sub-nets, smaller groups of users that are formed within the total user environment, all ultimately connected to the same network. The radiating cable provides a convenient means of segregating these groups, by customizing the coverage. This is demonstrated in Fig. 7, in a simple WLAN/radiating cable scheme [2].

Because the radiating cable coverage is tailored to the specific area, interference between sub-nets and other WLAN

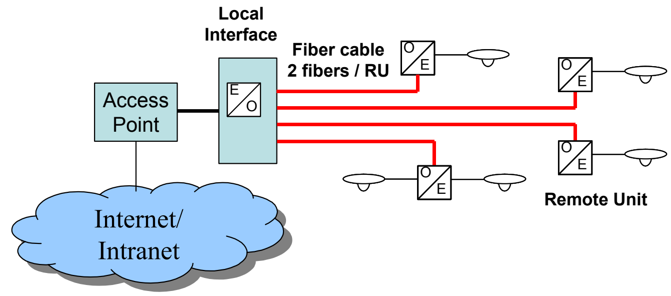

Fig. 8. WLAN access point connected to a fiber-optic DAS.

networks is minimized. WLAN systems using radiating cables are deployed e.g. in hospitals and warehouses [2].

Finally, in Fig. 8 a simple example on a WLAN access point connected to a fiber-optic distributed antenna system is given.

B. *Connecting WLAN Into Multi-Operator/RAT DAS*

When WLAN is integrated into a multi-operator or multi-RAT DAS, a few things have to be considered. First of all, when the same DAS is used to carry both WLAN and some cellular system, e.g. GSM or WCDMA, the required bandwidth is normally larger than what a digital fiber-optic DAS can offer. Secondly, the differences in the required dynamical range may set further limitations even on the analogue fiber-optic DAS. Finally, due to the quite limited output power, a WLAN access point cannot be connected to as large passive coaxial DAS as the cellular systems.

Next, two commercial WLAN DAS solutions, WLAN Distributed Antenna System (WDAS) [1, 10, 11] and ModuLite™ [7, 8] are briefly presented.

WLAN Distributed Antenna System

One key component of the WLAN Distributed Antenna System (WDAS) is the WLAN Injector, which makes it possible to insert a WLAN (802.11b, 802.11g) signal directly from an access point into an existing DAS supporting one or multiple cellular systems, e.g. GSM/GPRS, EDGE, WCDMA and CDMA2000. Signals can be inserted from several different WLAN access points throughout the building, one access point for each injector, and then distribute the signal from each access point to a specific section of the building. Usually, each section will be covered by two or more antennas. The WLAN Injector is carefully designed to minimize the path loss for both WLAN and the cellular signals. The injector also provides high isolation between the WLAN access points and cellular base stations, and effectively eliminates the risk of the systems interfering with each other's performance.

In a typical WDAS implementation, the APs are connected to the DAS in a floor-by-floor basis, see Fig. 9. This is necessary due to the limited output power of the AP (100 mW).

The advantage of the WDAS solution is that it can provide as much coverage as needed using one access point, and the incremental cost of modifying the existing in-building DAS

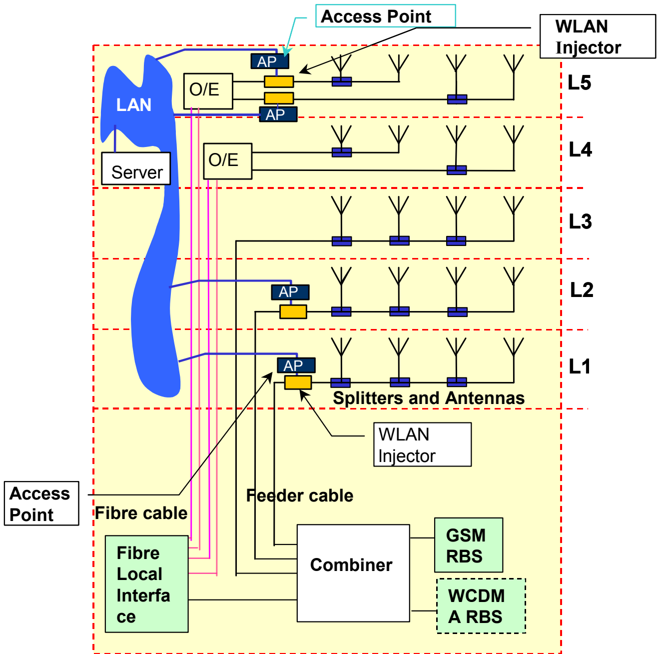

Fig. 9. Overview of the WLAN integration with the cellular (hybrid) Distributed Antenna System.

infrastructure to support WLAN is minor. With fewer access points needed to get good coverage, it reduces the cost of deploying WLAN. According to [1] the DAS used for GSM coverage is able to reduce the number of WLAN APs by 30-70%.

ModuLite™

The ModuLite's™ hybrid fiber coaxial modular architecture is designed to enable multiple wireless services to be distributed using a single common cabling infrastructure. The cabling infrastructure includes a fiber-optic cable, a single coaxial cable, and a single antenna.

The ModuLite™ has the following benefits and features:

- Single cabling and antenna system for all services
  - Enables fast deployment of a new service.
  - Reduces tenant disruption.
  - Simplifies maintenance.
- Upgradeable to include more than ten services per Modular Remote Cabinet (MRC), including 3G technologies.
- Eliminates RF interferences occurring in parallel infrastructures due to cross antenna coupling.

The ModuLite™ (see Fig. 10) has two main components, the MBU (Modular Base Unit) and the MRC (Modular Remote Cabinet). Both components are designed such that they can be located in easily accessible area, such as the communication room, the communication closet, or in the riser.

The MBU converts RF signals from the RF source (Base Stations/Repeaters) to an optical signal using direct modulation technology. The MBU is then connected via a single mode fiber-optic cable to the MRC.

The MRC is comprised of RF modules (MRU's), each

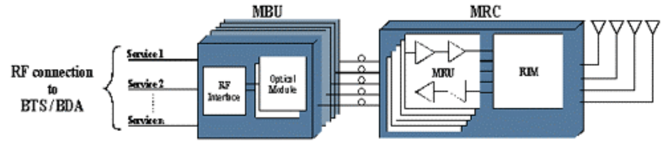

Fig. 10. ModuLite™ block diagram.

supporting two to four services, depending on the application. Each MRU module has sub-RF channels in order to maximize the performance of each specific service in terms of IMD suppression and dynamic range. Each MRC can contain five MRU modules, hence at least ten services. The modules can be added as required to support the required services. The MRC converts the optical signal to RF, performs filtering and enhanced signaling via its Remote Interface Module (RIM), and connects to a single antenna via a single coaxial cable.

The ModuLite™ supports two types of system configurations for WLAN:

1. Access point per Modular Remote Unit.
2. Access points centralized at the MBU location.

In order to compensate for the excessive propagation loss of the WLAN resulting from its high frequency (2.4 GHz frequency band compared to licensed services' frequencies typically in the 800 – 2.1 GHz frequencies), the MRC provides sufficient amplification for the WLAN RF carriers. This results in the same footprint coverage as the licensed services.

V. Recent Research Issues

Today, 90-95% of all in-building DAS installations for cellular radio systems use passive coaxial cable distribution networks. The main reason for that is the cost of fiber optics, which is in general cost-effective only for link spans longer than 100-200 m. The cost is a major obstacle to a massive implementation of fiber-optic DAS. Low-cost technologies that can be used include VCSELs (Vertical Cavity Surface Emitting Laser), standard TO-46 packaging, standard or wideband multi-mode fibers, and low-cost connectors for datacom [4]. A majority of these components are developed for low-cost fiber-optic data links (e.g. Gigabit Ethernet) and it is therefore important to investigate the analog performance of these components and then optimize them for analog applications. Key issues are e.g. the development of low laser noise (Relative Intensity Noise, RIN) and high linearity VCSELs, low-cost pre-distorsion circuits, and impedance matching of low-cost packages to increase their useable frequency range [4].

One topic for research activities looking for low cost FRUs has also been the *passive optical picocell*. In this concept the RF-signals are carried to and from passive picocell base-units by optical fibers. The base-units are small devices that perform light-to-radio and radio-to-light conversion. Uniquely, they require neither a power supply, nor batteries.

Like the traditional DAS this passive picocell technology can support simultaneous communication using a range of different radio technologies.

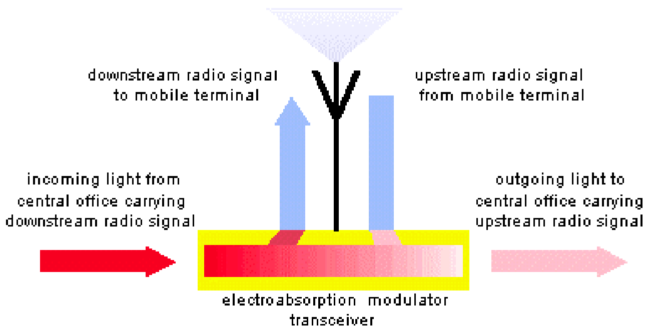

Fig. 11. EAM transceiver.

The base-unit is a self-contained opto-electronic component that connects to a pair of optical fibers and an antenna. The technology at the heart of the passive picocell is the electro-absorption modulator (EAM) – an opto-electronic component capable of acting as a passive transceiver for radio signals carried on light-waves which themselves are carried on optical fiber (radio-on-fiber), see Fig. 11. The EAM contains an optical waveguide in which the optical absorption varies with the electric field. This absorption means that the device acts as a photo-detector for the downstream signal (the light generates a photocurrent at the radio carrier frequency). The detected radio signal is radiated into free-space by the built-in antenna, to any mobile terminal within range. The light that is not absorbed is re-modulated by the electric field of the up-steam radio signal to be carried back to a "central office" by an optical fiber. A conventional photo-diode at the central office converts the signal back to a radio frequency signal that is down-converted and demodulated as usual. Both functions, photo-detection and modulation, can occur simultaneously in the EAM, which means that it can act as a full-duplex transceiver.

More information on the passive optical picocell and EAM can be found for example in [12] and [13].

Microwave Photonics has developed an initial suite of products around a new *switched DAS*, called AgilWAVE™ [14] In an AgilWAVE infrastructure a small, inexpensive distributed antenna unit, called the AgilWAVE Antenna POD™ is used to provide uniform, targeted coverage. Each Antenna POD receives a broadband signal from a centrally located AgilWAVE Wireless Switch™, which is a radio PHY-Layer device that can route signals to and from any base station to any of the Antenna PODs via optical fiber. Through the AgilWAVE Wireless Switch, each Antenna POD can transmit and receive up to 35 separate carrier signals simultaneously, in either the 2G, 3G or Wi-Fi bands. If a particular cell is experiencing congestion, the AgilWAVE Switch uses a technique called re-sectorization to change the mapping of multiple base station sectors to that and surrounding Antenna POD, relieving congestion. Conversely, if Antenna PODs are underutilized, the AgilWAVE Switch can share base stations sectors to increase trunking efficiency. By controlling the RF power output of each Antenna POD, the AgilWAVE Wireless Switch enables each service and coverage cell to be optimized for best performance and minimal interference [14].

VI. Conclusion

Many of the WLAN hotspots are significant in size and achieving good coverage and capacity may be challenging. The current standard for providing coverage is to distribute individual WLAN access points in the target area. Due to the fact that the in-building environment has many challenges, such as walls and elevators, the number of access points needed by using this method may become significant.

There are several benefits of implementing the WLAN over a DAS. For example, the WLAN coverage and capacity can be improved and the coverage area can be shaped in a more efficient way. Furthermore, the integration of WLAN with the existing cellular DAS will reduce hardware and related installation cost and services dramatically compared to two stand-alone networks.

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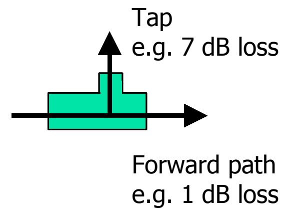
HOMEWORK 18.5.2004

1. See the passive antenna network shown below. Define the tap and forward path loss values (in dB) for power tappers X and Y so that the radiated power is the same for all three antennas. Assume that the power tappers are ideal, i.e. have no additional (internal) losses.

   Loss for cable A: 7 dB/100 m
   Loss for cable B: 11.3 dB/100 m
   Antenna gain: 2 dBi



2. Assume the balanced passive antenna network from 1 (thus, including the "tuned" power tappers). Calculate the radiated power per antenna (EIRP) if the transmit power is equal to 20 dBm at the input (Z) of the antenna network.