Nicolas Sklavos · Michael Hübner
Diana Goehringer · Paris Kitsos *Editors*

System-Level Design Methodologies for Telecommunication

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Chapter 1
Indoor Radio Design: LTE Perspective

Spiros Louvros, Vassilios Triantafyllou and George Asimakopoulos

Abstract Long-term evolution (LTE) indoor coverage is becoming important day by day due to multilayer design and high traffic-building premises. Nowadays, it is true that user expectations from operator's indoor high-quality services and capacity availability provides a well-promised opportunity to offer improved LTE services with appropriate traffic revenues. Customers expect indoor faster Internet connections than ever and they would not tolerate slow connections. Wireless network indoor capacity for data services will become more important in the near future. As a result, indoor LTE radio design is one of the key elements to provide a high-quality service to meet the user demand for a high-capacity mobile network.

1.1 Introduction

This chapter will provide a complete radio design perspective for indoor long-term evolution (LTE) services supporting all available mobile network standards. In order to have a complete and interference-free design, indoor antenna is important. This antenna could be used for indoor services over all mobile standards (LTE, High Speed × Packet Access (HSxPA+), wideband code division multiple access (WCDMA), and global system for mobile communications (GSM)) together with nonmobile standards (wireless local area network (WLAN)). Radio sharing could also be the case where same infrastructure could be used by several operators. In the same way, a total new radio deployment idea could also be used in order to have a completely interference-free radio environment; this is the use of visible light communication (VLC) also known as WiLi solution. In such a solution, all antenna infrastructure is replaced by power light-emitting diodes (LED) lights and indoor LTE coverage

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is provided solely by light sources. Generally speaking, indoor radio design might be possible for new indoor projects, design of single-operator indoor antenna infrastructure, multioperator indoor design, or multinetwork design including LTE, WCDMA, GSM, and/or WLAN. From design process point of view, indoor radio design might be similar to the macro-cell outdoor design; however, some specific aspects must be emphasized. Of course, site acquisition is not needed where indoor coverage objective is clearly identified.

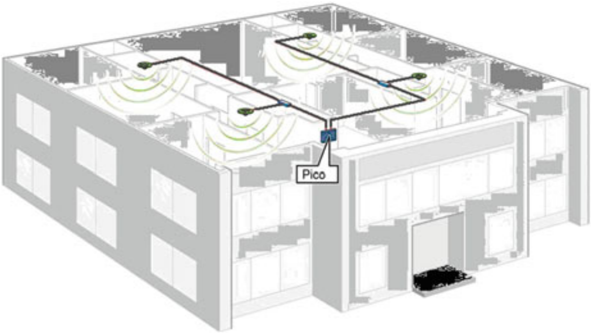
Proposed indoor process or technique selection depends on coverage and capacity requirements definitions. Proposed solution thus is selected based on the signal strength and signal quality targets, number of indoor walls and construction material, number of floors, floor layout, and dimensions. In such design process, the decisions concerning the type of the distribution network and the number of antenna heads are also important. The positions of the antennas are planned considering practicable solutions and the results of prediction calculations. When preliminary indoor design is completed, building details should be verified and all installation concerns and facility availabilities should be considered carefully. Practical limitations should also be considered into proposed planned configuration and the use of measurement tools should be proposed, evaluating and approving coverage and interaction (interferences) between planned system and existing macro-cell outdoor coverage. After appropriate installations, planning issues and antennas' location selection, signal strength loss distribution should be measured separately for each antenna resulting into required indoor transmission output power. Last concern should be the indoor network capacity, showing explicitly the needs on number of cells, antenna tilts, cell directivity, and sectorization.

1.2 Preliminary LTE Indoor Design Requirements

When planning for indoor coverage and services, it is important to realize that a distributed antenna [1] system will have to be used for micro, pico, or femto cells, as presented in Fig. 1.1. European-Union (EU) and 3G Patent Platform (3GPP) standards have to be followed and all spectrum requirements should be designed fulfilling and respecting these standards. Antennas and radio design proposals should be compliant with current baseline and future technologies plus the operating band requirements. Moreover, all passive components (feeder systems, combiners, splitters, and antennas' equipments) should be compliant with future technologies such as visible light communications (VLC). Coverage expectations provide all necessary restrictions for primary radio-frequency (RF) design criteria and are defined by the respective reference signal strength provided most often by the operator. Specifically from indoor perspective, indoor coverage is typically defined by both downlink and uplink signal strength and vary by access technology layer for corporate and public sites.

To overcome any future expected problems on accessibility or signal strength coverage, it is recommended that all indoor antenna-distributed networks should be planned using multiple sectors. For each sector separate planning should follow

Fig. 1.1 Indoor coverage example, using pico-cell antennas



GSM 900, Digital Cellular Service (DCS) 1800, Universal Mobile Telecommunication System (UMTS) 2100, LTE 2600 MHz, and WiFi frequency bands and number of sectors and antenna branches will be dependent on both the architectural constraints as well as the Single Input Single Output/Multiple Input Multiple Output (SISO/MIMO) capacity requirements. During planning process, data services should be guaranteed [2]. Consequently, a general rule of thumb might be that signal strength level of −90 dBm in 90–95 % of coverage area should be provided with adequate carrier-to-interference (C/I) level of minimum 9 dB. Worst radio conditions will result into very low throughput and low-service integrity. As an example from real drive tests, orthogonal frequency-division multiplexing (OFDM) resource block (RB) throughput versus signal-to-noise and interference ratio (SINR) curve is provided in Fig. 1.2. It is obvious that as long as SINR is kept low because of bad indoor planning, expected throughput per RB falls below 10 kbps [3].

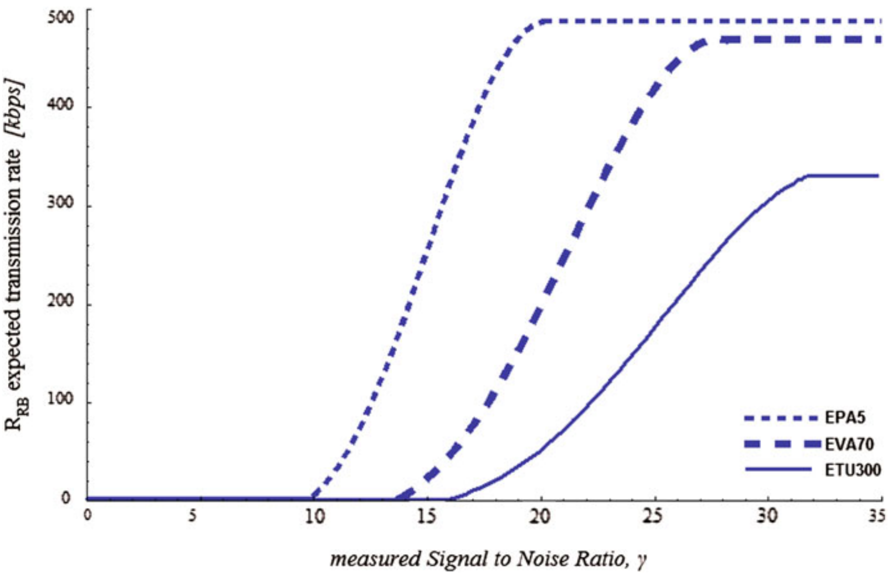


Fig. 1.2 Expected transmission rate per RB versus signal-to-noise ratio γ

Specifically for LTE planning, certain requirements should be fulfilled [3]. First of all, the reference signal received power (RSRP) should be better than 85 dBm in 90–95 % of indoor coverage. Quality should also be guaranteed, so that the reference signal received quality (RSRQ) should be higher than − 10 dB. Specifically, when multisector design is preferred and in overlapping locations, server dominance should be guaranteed in order to reduce the waste of network resources and network performance degradation. To guarantee such a criterion reference signal (RS), signal strength levels on OFDM physical layer of dominant server, among several overlapping sectors, should be at least 6 dB stronger.

When coexistence of LTE with UMTS/HSxPA is a case, then the following criteria should be fulfilled. First of all downlink CPICH_RSCP power should be better than − 80 dBm in 90–95 % of indoor environment. Moreover, quality on CPICH_Ec/No should be higher than − 10 dB. Dominance with one strong server in overlapping locations should also be guaranteed. In 3G systems, dominance is a function of pilot pollution, a reference measurement on degradation in CPICH_Ec/No of best pilot server in the presence of other pilot signals. As a general case, in locations where there are more than three strong servers, pilot pollution is considered to be bad. Whenever only two dominant servers exist in the desired planned location, CPICH_Ec/No of desired dominant server should be 5 dB stronger than CPICH_Ec/No of neighbor server.

1.3 Planning Area Surveys

Planning prerequisites [2] have to be followed by indoor surveys. Preliminary design will have expected antenna locations, cabling, and assumed equipment locations. Sometimes repeaters might be needed, consequently extra planning requirements and equipment locations should be guaranteed. Signal strength confirmation is evaluated or estimated either by system simulations or by real drive tests using a test transmitter and receiver per expected antenna locations. Whenever repeaters are used, RSSI for GSM/LTE or Pilot Power for WCDMA at the donor antenna should be measured on the roof. Specifically for GSM solutions, broadcast control channel (BCCH) frequency along with the base station identity code (BSIC) should also be identified. Moreover, outdoor-to-indoor coverage in the indoor area from surrounding sites should be measured and reported.

To avoid coexistence interradio technology interference, a detailed outdoor-to-indoor planning report should be prepared regarding all available BCCH with BSIC as presented in Fig. 1.3. This will help to determine the design thresholds required as well as identify the handover locations.

Sometimes, the expected antenna system and site/sector locations might not be adequate. In such scenario, planners should have an agreement with the operator regarding possible alternative locations for cabling, mounted distributed antenna system, or communication E-UTRAN Node B (eNodeB) equipment. After final location surveys, required locations of all the distributed antennas on each individual

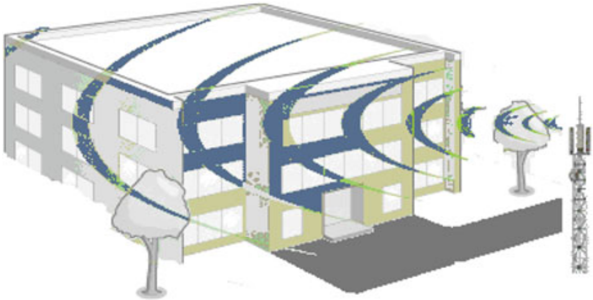


Fig. 1.3 Expected transmission rate per RB versus signal-to-noise ratio γ

floor should be decided. Information regarding building characteristics should be acquired for future installations as shown in Fig. 1.4.

Ceiling type is important indicating possible areas requiring special attention due to decorations, sensitive areas, etc. Impenetrable obstacles should be explicitly indicated, specifically for locations with supporting building walls, steel concrete partitions, etc.

1.4 LTE Indoor Coverage Design

The most common proposed and preferred solution for indoor coverage design is the use of a number of dedicated base stations as presented in Fig. 1.5 [4]. It is in general a solution with good performance results for indoor coverage on large buildings,

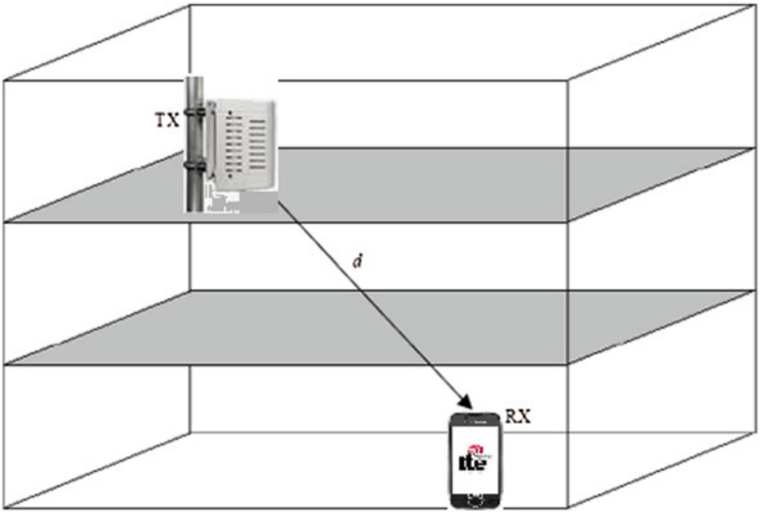


Fig. 1.4 Buildings characteristics for indoor planning

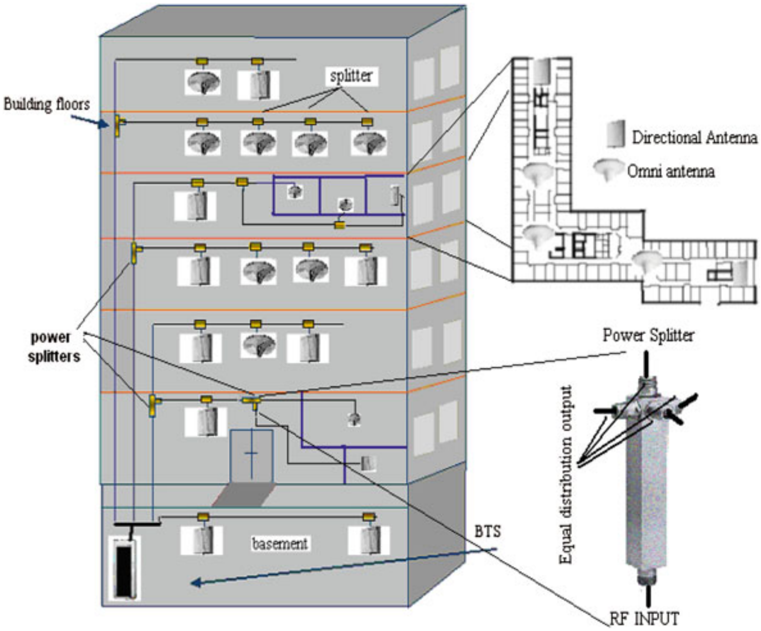


Fig. 1.5 Indoor coverage with number of distributed antennas

malls, airports, university campuses, and metro business district areas. It is supposed to be a good solution since nominal planning is performed, something that most cell planners already know very well, where both coverage and capacity are fulfilled. Moreover, interference analysis is successfully defined and signal strength received levels are confirmed. This is a solution quite often radio designers prefer in order to optimize multilayer network coverage design by optimizing indoor coverage and offloading capacity of existing indoor-to-outdoor macro cells. General rule of thumb [1] is to connect one eNodeB sector output power to a distributed system of antennas as presented in Fig. 1.5.

In such configuration, several distributed components are used extensively such as coaxial feeder cables, omni or directive antennas, hybrid couplers, and power splitters.

However, in order to increase capacity, if required because of extensive traffic load on some floors or areas of indoor location, a good solution might be to use several eNodeBs and sectorize them per floor or number of floors as shown in Fig. 1.6. If this is the case, the implementation cost is increased; however, the capacity profit overcomes any other disadvantage.

Specifically for tunnels or underground metro tubes [1], another solution might be the leaky cables (a specific design of radiating feeders). The main disadvantages of such a solution are high losses and short range. Indeed, losses are dependent on carrier frequency and coverage range is limited longitudinal to few hundred meters

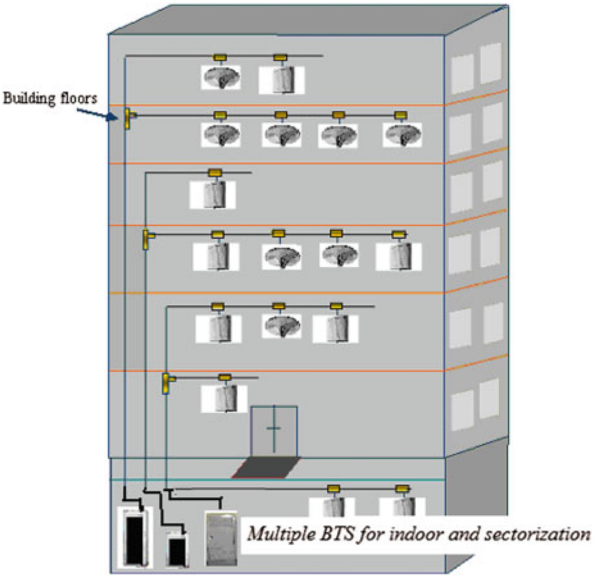


Fig. 1.6 Indoor coverage with use of multiple eNodeBs

and transversal to few ten meters. This is however adequate for most of the tunnel or underground applications. In special cases of longer distance coverage, leaky cables are not recommended and active antenna-distributed systems are rather preferred and standardized, see Fig. 1.7. eNodeB is split into two subsystems, the base band unit (BB, responsible for all base band functions such as modulation, coding, and signal processing) and the radio remote unit (RR, responsible for the radio functionality as power amplification and filtering). Splitting is important in order to place BB and RR unit in different locations. BB unit could be placed close to the main base station equipment and the RR unit side by side to the antenna system inside the tunnel. In the past, most of the BB units were connected to RR units through feeders; however, losses were high and either repeaters or high initial power was needed. Nowadays,

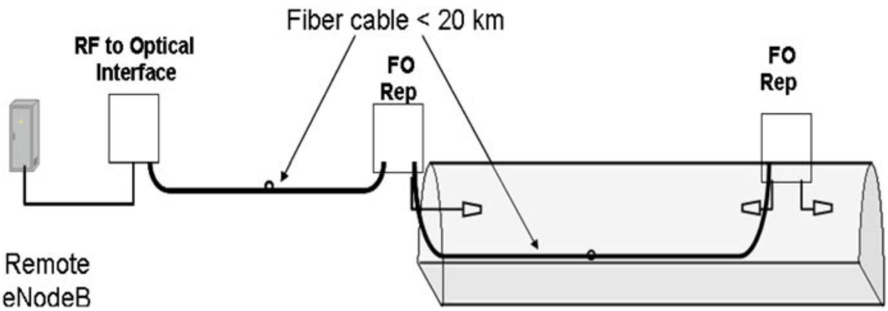


Fig. 1.7 Indoor coverage using fiber optics and repeaters

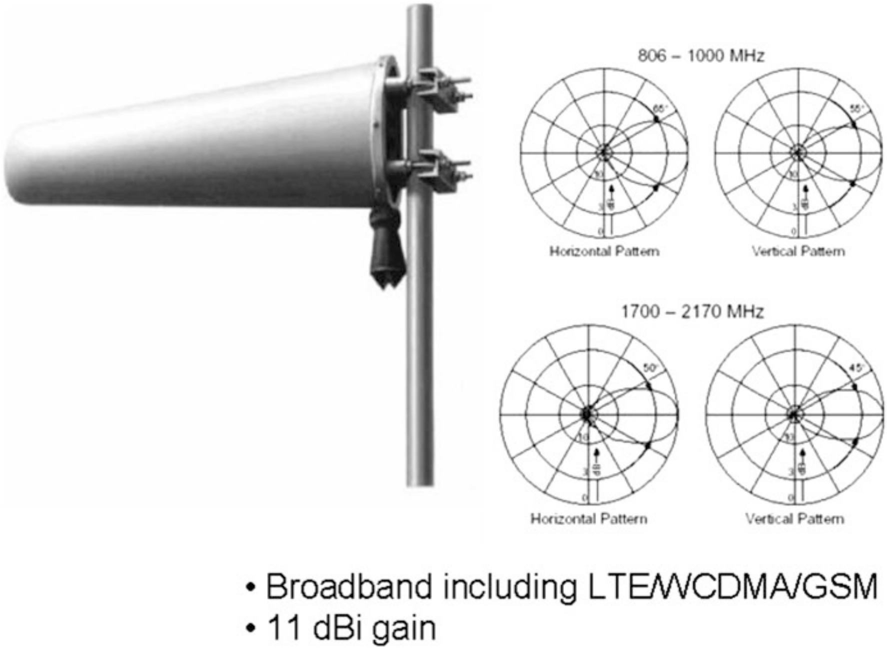


Fig. 1.8 Indoor in-tunnel coverage antenna type with its radiation characteristics

however, the preferred solution is the RF to optical transmission with the use of optical fibers in order to eliminate passive losses.

Types of antennas [5] are extremely important in such scenario since directivity and gain are very crucial. In Fig. 1.8, a typical antenna with its radiation characteristics is presented.

Fiber optics [1] could also replace main transport domains for metro and indoor planning when large buildings are involved or when multiple buildings are to be covered, mainly in metropolitan areas, as presented in Fig. 1.9. This is extremely recommended since optical fiber infrastructure is already installed and available.

According to Fig. 1.10, cell planners should always remember that outdoor-to-indoor interference should be kept at low levels.

Another important parameter is the antenna directivity [5] and radiation diagram in indoor planning cases. Indeed, for indoor coverage directional antennas should be used depending on the indoor topology. However, due to radiation patterns there are areas of low coverage even though user is close to the antenna. For directional antennas with twin lobes or omni antennas, low-gain area is right below the antenna; hence planners should avoid placing the antenna in such a location (wall mounted or ceiling mounted) that important coverage indoor spaces suffer from low gain. According to Figs. 1.11 and 1.12, on the other hand when directional antenna with on lobe is used [4], the low-gain area is on the diagonal of the main lobe.

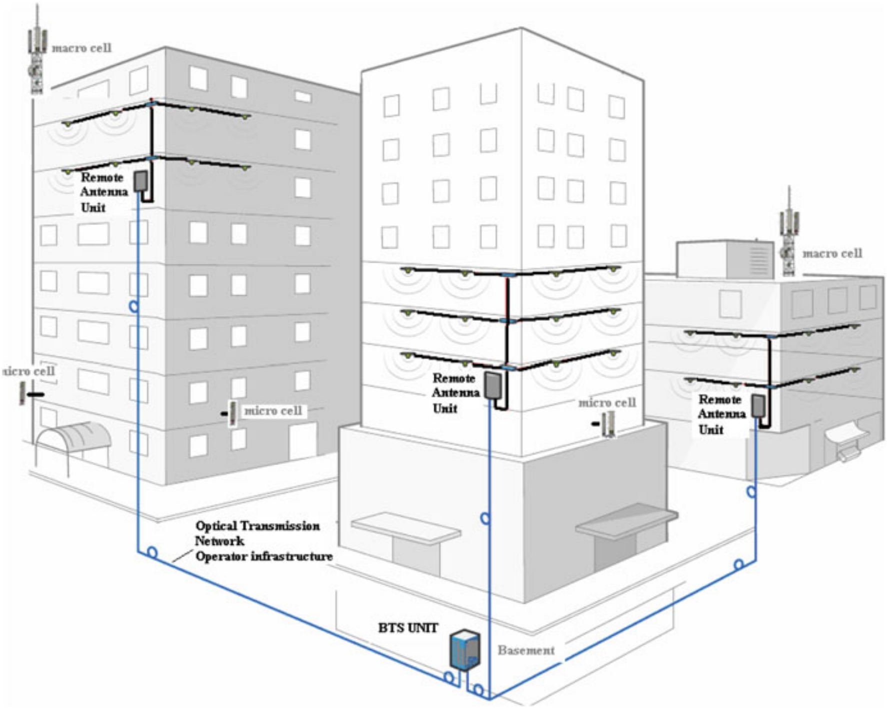


Fig. 1.9 Indoor coverage with fiber optics metropolitan transport network

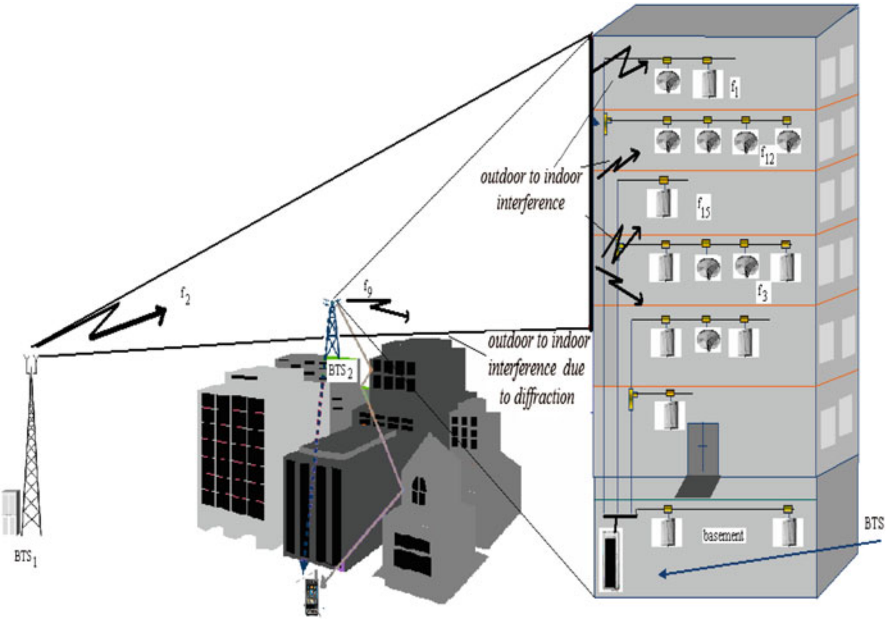


Fig. 1.10 Outdoor-to-indoor potential interference

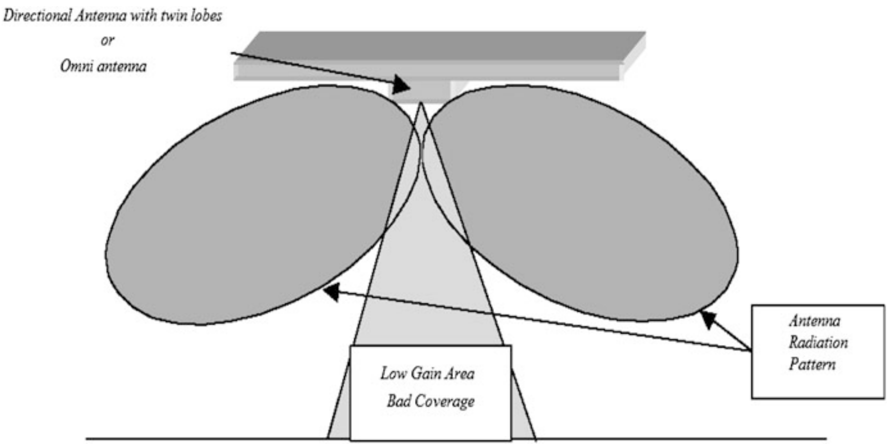


Fig. 1.11 Omni- or twin-lobe directive antenna low-gain coverage area

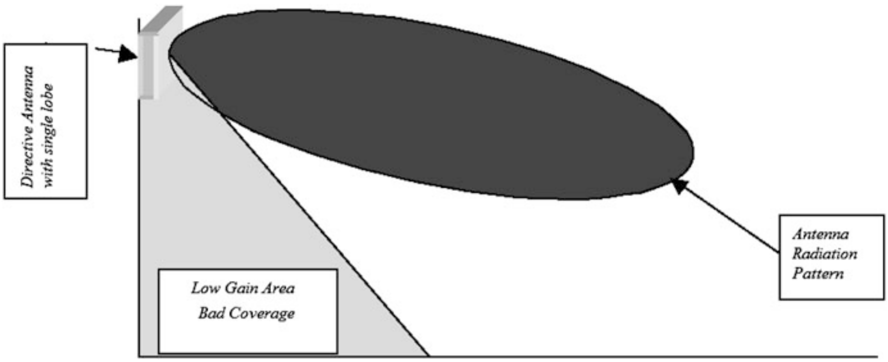


Fig. 1.12 Single-lobe directive antenna low-gain coverage area

If radio designers would not like to use optical fibers or leaky cables in order to provide indoor coverage in tunnels or underground areas, another well-known and wide-spread solution are the radio repeaters [1]. Radio repeaters rely on an outdoor donor eNodeB antenna used for outdoor communication with existing outdoor coverage and an indoor service antenna that aims to extend original outdoor coverage into indoor areas. The repeater amplifies the received signal from outdoor antenna and transmits it via the other indoor service antenna. The signal amplification enables both mobile users and the Base Transceiver Station (BTS) to receive a better signal strength. Consequently, repeaters only extend the coverage of a particular cell (the donor cell) to locations that were not originally part of the coverage of that cell. In Fig. 1.13, a donor–repeater pair is presented together with RF to optical interfaces using fiber optics.

The main disadvantage of using repeaters is the capacity overloading since they do not provide any additional capacity and on the same time they do not allow offloading the macro cell from which the donor antenna picks up the signals. As

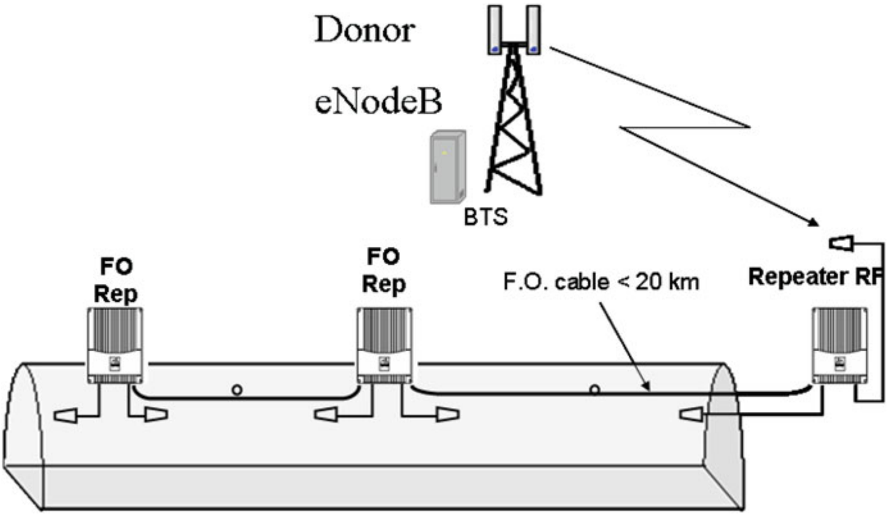


Fig. 1.13 Donor–repeater indoor—in-tunnel coverage scenario

a rule of thumb: whenever RF repeaters are used, capacity planning of outdoor donor cells should be reconsidered and increased, otherwise traffic congestion and performance degradation might be expected. Another disadvantage is interference. Indeed, when extending the outdoor coverage into indoor areas, it might disturb the frequency planning by extending specific carriers into unwanted areas outside in-building coverage; this is something planner should always keep in mind. The main advantage of using repeater is the low implementation cost, the use of regular transmission equipment, and the enhancement of indoor coverage with fairly easy deployment. From coverage perspective, coverage improvement may be assured in a short time with low cost.

According to Fig. 1.14, another possible solution [1] might be the use of leaky cabling as the serving antenna.

Generally speaking, radio repeaters are widely used for indoor coverage expansion and optimization. Indoor expansions using repeaters are widely used when external outdoor network is not able to provide a satisfactory service in certain conditions. Specifically for data services on WCDMA or LTE coverage scenarios, where low SINR is the dominant case, repeaters are recommended. Moreover, in dense urban areas with high building factor, lower floors usually suffer from low signal strength due to penetration pat losses. Repeaters are quite often proposed and used to expand coverage. Also, fast data delivery service depends mostly on signal levels and on medium access control (MAC) scheduler decisions. Expanding indoor coverage improves capacity and throughput performance, especially for high-speed packet access (HSPA), evolved high-speed packet access ($HSPA^{+}$), and LTE. Nowadays, they are used for in-building coverage expansions, underground expansions, in-tunnel coverage, in-train coverage expansions, in-airplane expansions, and of course for near-cost ferries.