Picocells

ERSLab

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Picocells

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and
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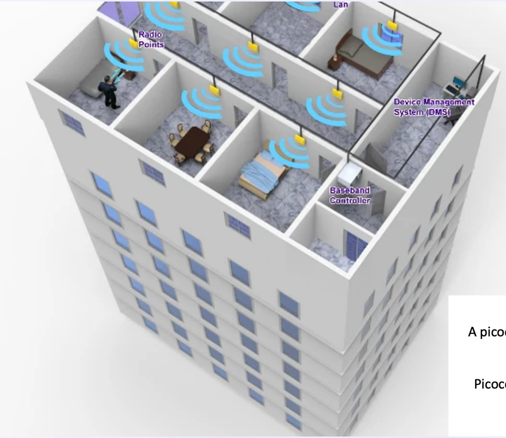
Outline

What is it ?



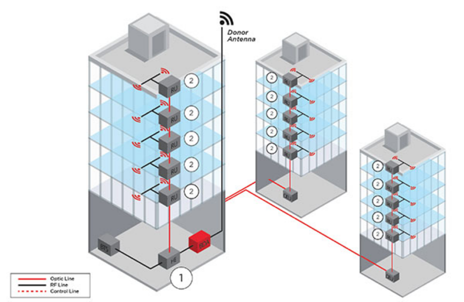
A picocell is obtained by locating the TX station inside a building.

Picocells in the otdoor environments are also possible.

Why we do care

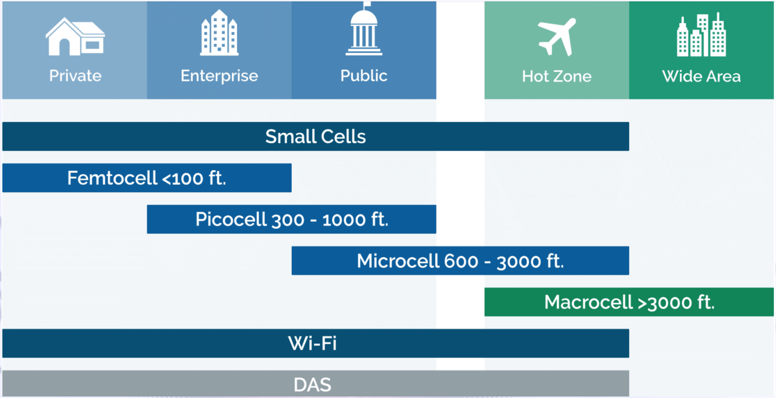
Very high traffic areas

They are increasingly used in very high traffic areas for cellular telephony:



- Office buildings;
- Railways;
- Airports;
- ...

Why we do care



A very difficult environment

Picocell propagation

It is affected by a variety of mechanisms that take place in a complex and 3D environment whose details are -in most of the practical cases - unavailable.

- Picocell propagation is a very hot-topic due to the growing importance of in-building high data rate communications.
- In the near future, the design of picocells is expected to rely on the use of semi-empirical models and engineering experience.

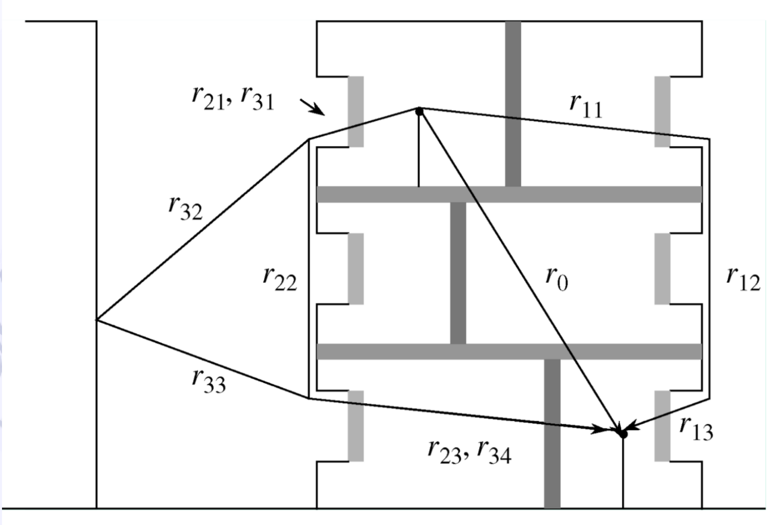
Outline

The legacy of measurements

Experimental evidence

1. Neither a simple power law nor a dual-slope model provide accurate enough fitting.
2. A more realistic empirical model shall account for the number of walls and the number of floors crossed.
3. The incidence angle plays a dominant role with near-normal incidence resulting in larger transmission through floors and walls.
4. The penetration loss exhibits a very complicated behavior wrt frequency, i.e.; it does not necessarily increase with increasing frequency.

Propagation mechanisms



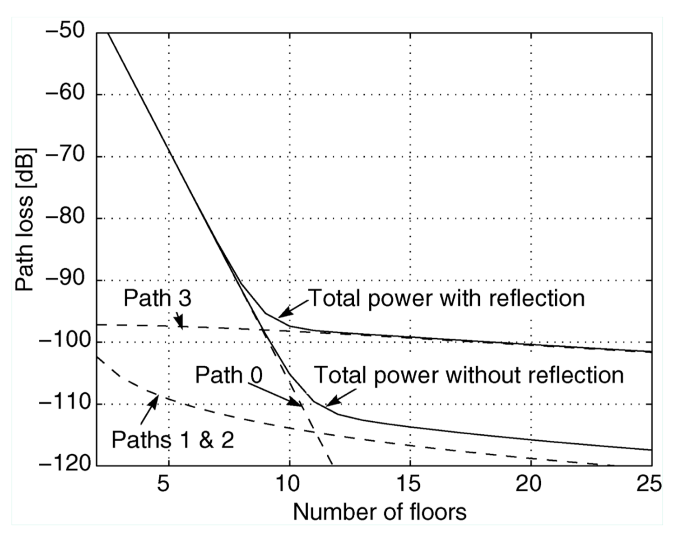
Propagation through floors

Propagation between floors

- Path 0 is the direct link that calls for attenuation due to floors.
- Paths 1,2 result in diffraction when propagating out of the window and again back in through the window. No obstructions related to floors.
- Path 3 calls for diffraction through the windows at an angle smaller than the previous paths, it is reflected by a nearby building and it is not affected by floors.

The electromagnetic problem can be addressed using GTD

Propagation through floors



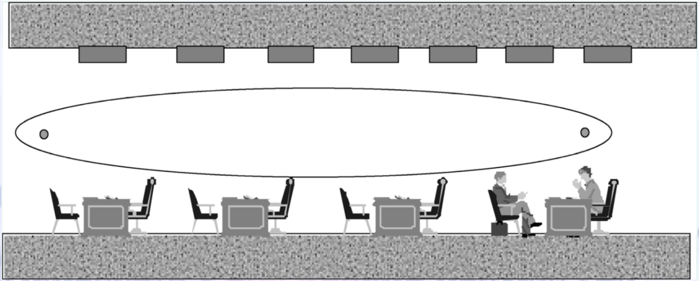
Propagation through floors

Two regimes apply

- When the number of floors separating TX and RX is small, the direct link dominates.
- At larger number of floors, the direct link goes down very quickly while the diffracting (1,2) and diffracting+reflecting (3) contributions tend to flat down.

Propagation on a single floor

The dominant mechanism is the LOS propagation



Fresnel zone

The antenna should be installed at the midpoint of the gap between the biggest ceiling and floor obstructions to result in the maximum unobstructed range.

Outline

Penetration loss

It is important to quantify the penetration loss

- Depth of coverage: to what extent the outdoor signal can be exploited to guarantee a desired QoS inside the building.
- When the outdoor signal is not enough, dedicated picocells are installed that reuse frequencies already allocated to other cells. Hence, one needs to quantify the possible interference of picocells with co-channel cells.

Penetration loss

Penetration loss is not at all a simple mechanism

- The simple Fresnel transmission coefficients do not explain the behavior of the penetration loss wrt frequency.
- The building's wall cannot be considered as a slab of lossy material.

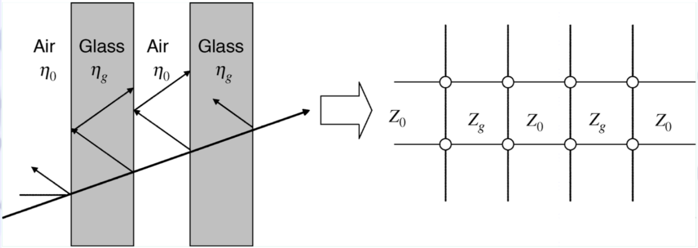
A holistic approach is needed

- The constitutive parameters of the material are frequency dependent even for relatively uniform walls.
- The wall's structure has in general several layers that result in interference and associated resonances.

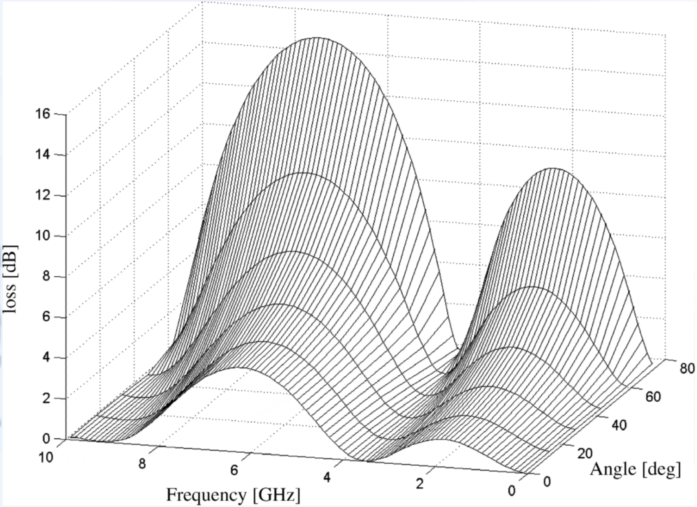
Penetration loss

Beyond Fresnel reflection coefficients

Each layer of the wall can be analyzed through an equivalent transmission line whose characteristic impedance depends on the wave impedance and the incidence angle



Transmission loss for a double-glazed window



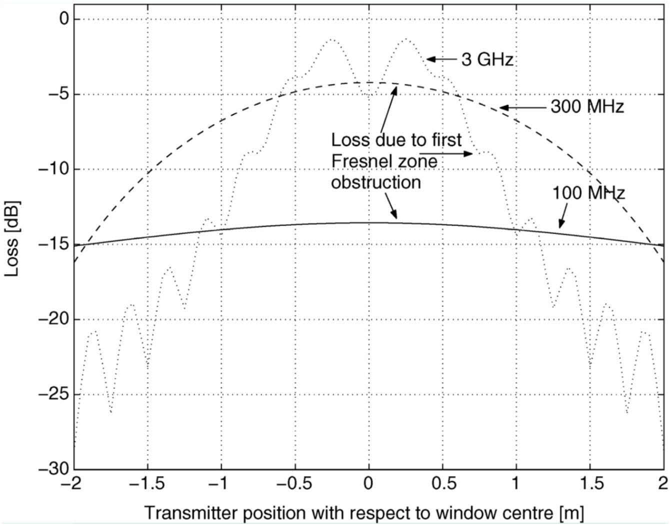
Penetration loss: the windows

The windows

The presence of the windows within the wall results in additional complications since the loss depends on the relative size of the Fresnel zone associated to the penetrating ray and the window's size as well as the glass material.

The penetration loss does not necessarily increase for increasing frequency as predicted by the simple Fresnel theory.

Penetration loss: the windows



Fading

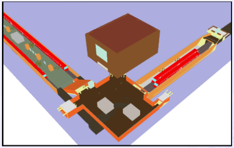
Slow fading (shadowing)

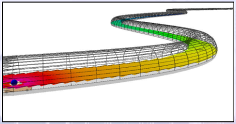
It results in a log-normal distribution as well as the other cell types. The location variability is however more environment dependent.

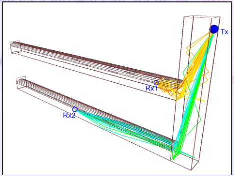
Fast fading

- The Rayleigh model is the most appropriate in most of the cases.
- The Doppler spectrum is flat since the direction of arrival is uniformly distributed in both azimuth and elevation.
- In most of the cases τ_{RMS} is much slower than the micro- or macro-cell one, although there is a larger spread wrt the median τ_{RMS} value.

Why we do care

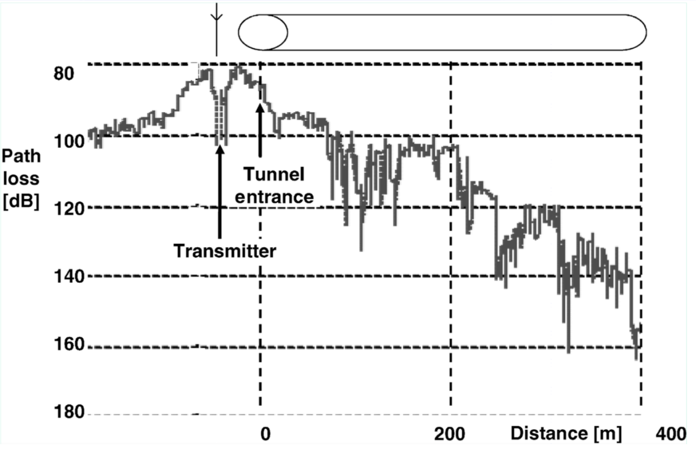






- There are a lot of commuting people using underground traffic infrastructures.
- Safety and protection, e.g.; in case of accidents it is important to have a reliable communication system.

Measured behavior from the train

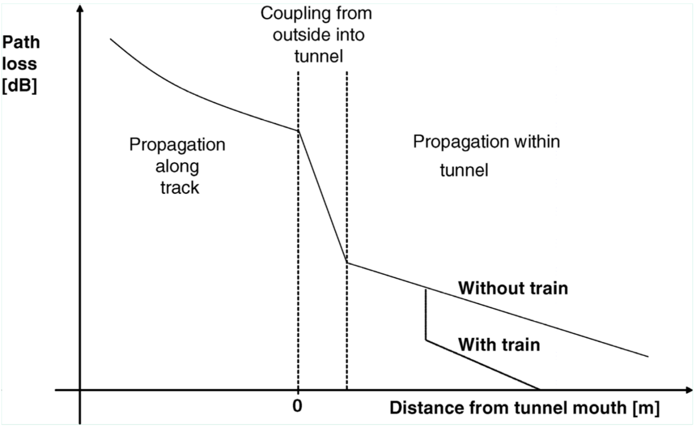


Measured behavior

A dual-slope behavior applies

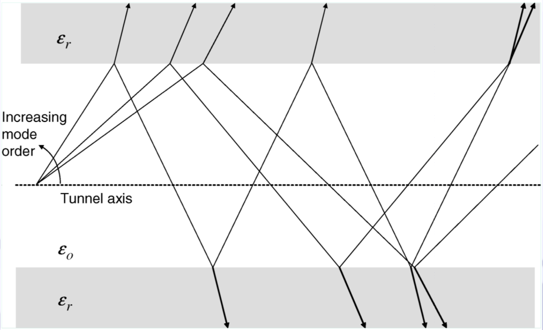
- The field drops rapidly in the few meters following entrance of the train into the tunnel.
- The drop depends on several issues:
  - The distance between the TX antenna and the mouth of the tunnel.
  - The angle between the antenna pointing direction and the symmetry axis of the tunnel.
  - The tunnel cross-section.
  - The frequency.

The main features appearing in tunnel radio-propagation



Outline

Tunnel propagation via multiple modes



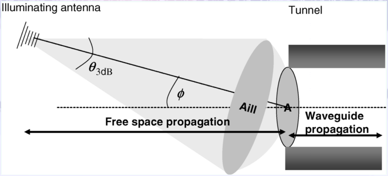
The tunnel acts as a lossy waveguide

Modes above a cut-off frequency can propagate with the loss decreasing with frequency (HP filter) above the cut-off.

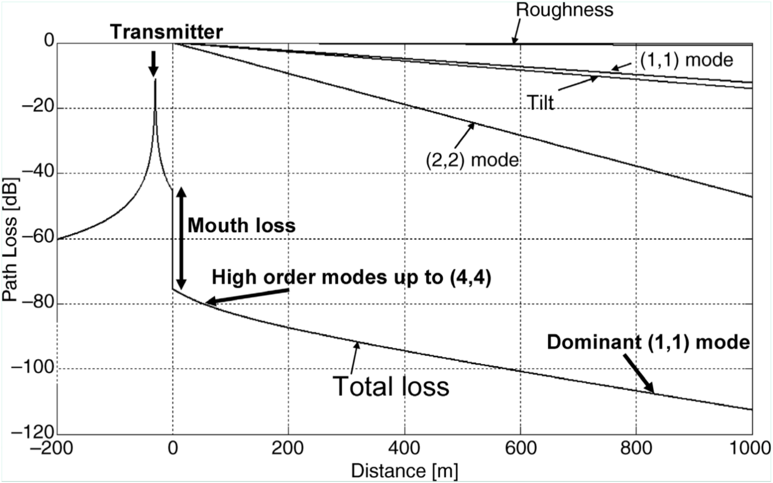
Tunnel propagation via multiple modes

Two additional issues must be included

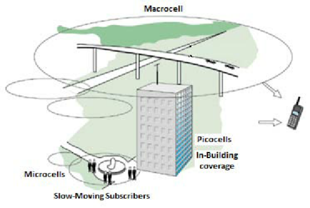
- The antenna (due to its size and the distribution of currents) does not act as a perfect exciter for the modes in the waveguide.
- When exciting the tunnels with and outdoor antenna, the beam cross-section must be projected onto the tunnel's mouth.



Overall losses in a tunnel @ 900 MHz



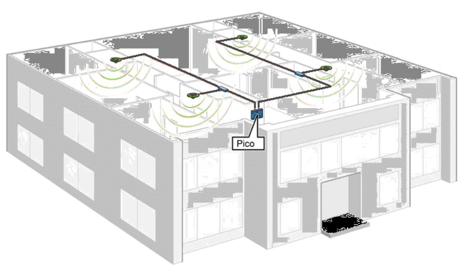
Why we do care



Illuminating the building from an external cell

- An external cell may cover several buildings.
- The cell capacity is shared among users across the whole cell area.
- The large variability of penetration loss may result is poor coverage.
- The coverage depth maybe inadequate due to channels sharing.

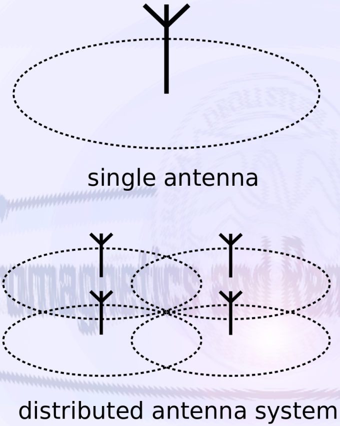
Why we do care



A dedicated system is needed

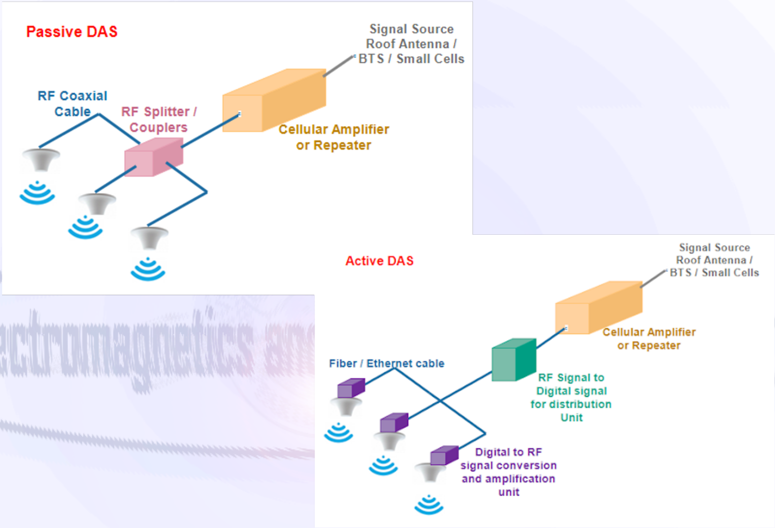
- To guarantee the desired QoS a dedicated picocell (or femtocell in the domestic environment) is needed.
- They have been largely used in airports, malls, railways.
- Nowadays there are frequently used in multi-tenanted offices.

Distributed antennas



- The TX power is split among several antenna elements.
- The total power is reduced.
- The is a larger probability of LOS connections.

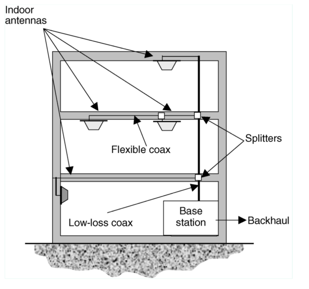
Distributed antenna system (DAS)



Outline

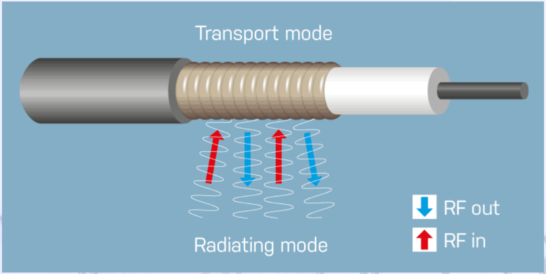
Passive DAS

The DA concept is implemented using a passive only infrastructure.



- The BS connected to the backhaul is located in an equipment room.
- The vertical distribution (across floors) consists of large-diameter coaxial cables.
- The horizontal distribution consists of smaller coaxial cables.
- Due to large losses, small-to-medium size buildings can be covered.

Leaky feeder



Radiating cable

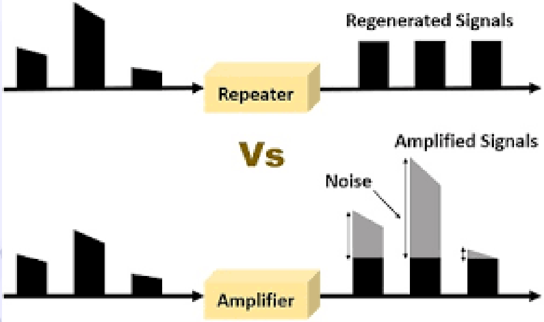
It is a special coax cable the is slotted along the longitudinal direction to allow radiation.

Leaky feeder

It is a useful low-cost passive DAS solution

- It is typically used for underground radio propagation, e.g.; tunnels, coal mines.
- It is also used in in-building applications, e.g.; long corridors and airport piers which are difficult to cover using conventional antennas.
- It is a good solution in terms of bandwidth (it is suitable for multi-operator design).
- The radiating cable should not be significantly influenced by furniture.

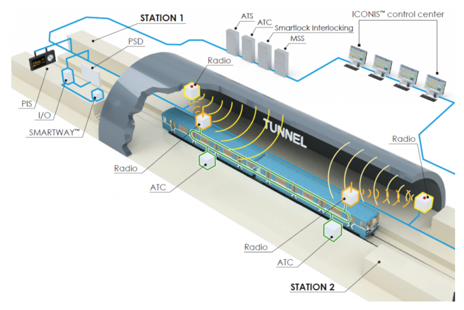
Leaky feeder



Repeaters/amplifiers are typically used

For ling tunnels, leaky-feeders are typically used together with bi-directional amplifiers or repeaters to cope with losses.

Communication-Based Train Control



Repeaters/amplifiers are typically used

Communications-Based train control (CBTC) is a railway signaling system that makes use of the telecommunications between the train and track equipment for the traffic management and infrastructure control.

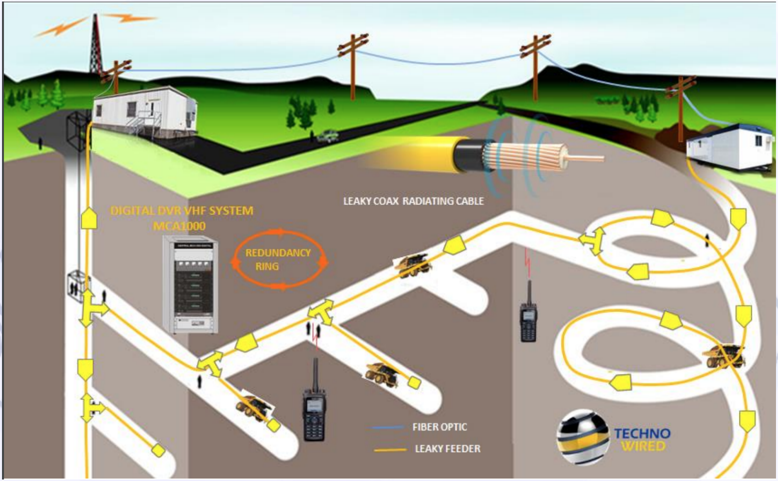
Leaky waveguide installed along a subway track

Leaky waveguide installed along a subway track

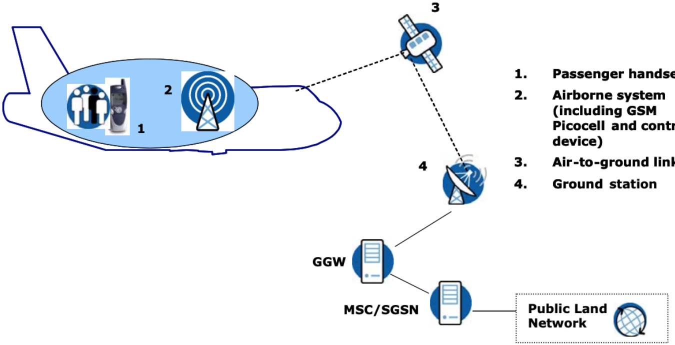
London tube

The service will use what is called a leaky feeder system - a large cable, laid in the small gap between the tunnel walls and the rail, that radiates the radio frequency we use to connect our devices.

Coal mine


DIGITAL DVR VHF SYSTEM
MCA1000
REDUNDANCY
RING
LEAKY COAX RADIATING CABLE
FIBER OPTIC
LEAKY FEEDER
TECHNO
WIRED

Mobile phone connectivity within airplanes

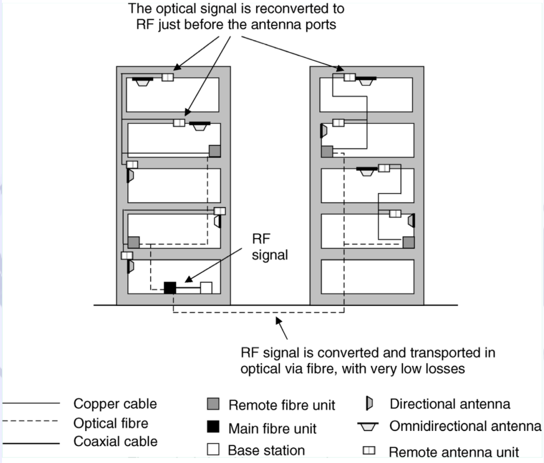


1. **Passenger handset**
2. **Airborne system (including GSM Picocell and control device)**
3. **Air-to-ground link**
4. **Ground station**

Outline

Active DAS

The DA concept is implemented using active amplification.



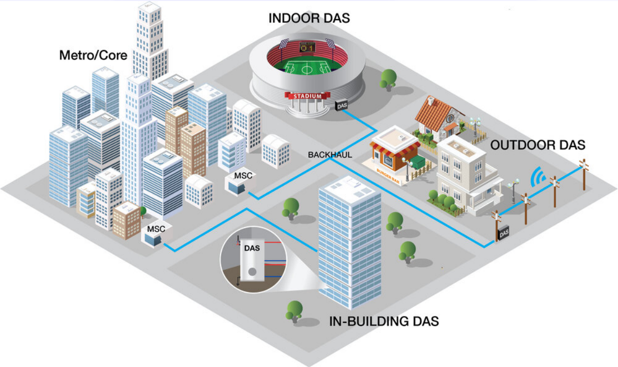
Active DAS

- Uplink amplification is typically placed closest to the antennas; while a distributed amplification is in place in the downlink.
- Frequency translating repeaters are used to convert RF signal into an optical one that can be accommodated over an optical fiber to reduce losses.
- Twisted pair copper is also used for the horizontal distribution.
- The optical signal is converted again to RF and connected to the passive DAS.

Optical backbone and RF passive DAS

The optical signal that travels over the fiber avoids the unwieldy coaxial backbone ensuring significantly larger coverage.

Base station hotel



BSH

A large number of building across a city can be connected to a centralized bank of base stations that is termed base station hotel.

Active DAS: NYC subway

Analog and digital signal distribution

The DAS systems analyzed so far distribute analog signals

- The approach is relatively low-cost and flexible;
- It introduces distortions, e.g.; loss, noise and distortions at various levels.

Digital signal distribution

It consists of transporting RF signals in digital format across a Local Area Network (LAN) using existing cable and switches.

- To work with reasonable low sampling rates, the digital conversion is applied to the base-band or near base-band signal.

Digital indoor signal distribution