SINGLE FREQUENCY NETWORKS

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Contents

Single Frequency Networks

1.1 Introduction:

Single Frequency Networks are the broadcast Networks where several transmitters simultaneously send the same single over the same frequency channel or we can say Single frequency network is the name given to a network of transmitters which have been specially treated to broadcast on one single frequency.

An example of this is DAB Digital Audio Broadcast where one frequency is used for each multiplex. Benefits are that transmitters combine to give stronger and more robust coverage.

Analogue FM and AM radio broadcast Networks as well as digital br oadcast Networks can operate in this manner. The aim of SFNs is efficient utilization of the radio spectrum, allowing a higher number of radio and TV programs in comparison to traditional multi -frequency network (MFN) transmission. An SFN may also increase the coverage area and decrease the outage probability in comparison to an MFN, since the total received signal strength may increase to positions midway between the transmitters.

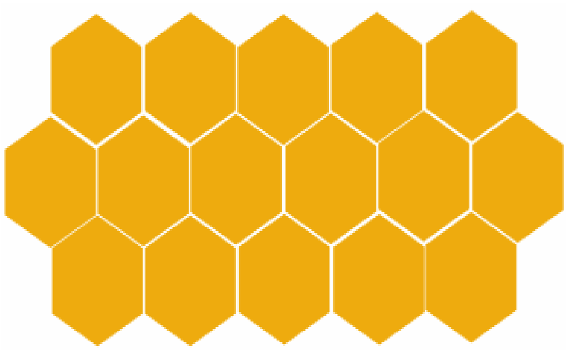

Fig 1.1 (a) SFN

Fig 1.1(b) MFN

Simply stated, single-frequency networks are when a broadcaster uses multiple transmitters to send the same signal over the same frequency. The idea is that in certain geographically -difficult areas broadcasters will have much better success if they can fill coverage voids by utilizing smaller, usually-less-powerful satellite towers in addition to their mai n tower.

It sounds like a simple idea, but, as always, the devil is in the details. Unlike the repeater towers that are sometimes used in western states (AKA translators), SFNs aren't simply receiving the signal, error-correcting, and retransmitting on a different frequency. That is an extremely inefficient use of the spectrum.

In a single–frequency network (SFN) all the transmitters operate at exactly the same frequency. Hence SFN requires much less spectrum than classical broadcasting networks because t here is no frequency allocation. In classical networks about 9 frequency band per program are allocated. SFN is believed to progressively replace classical broadcasting networks in future.

1.2 Principle of SFN:

In SFN, all transmitters are synchronously modulated with the same signal and radiate same frequency. Due to the multipath capabilities of the multi -carrier transmission system (COFDM) signal from several transmitters arriving at a receiving antenna may contribute constructively to the total wanted signal.

However, the limiting effect of SFN technique is so called self interference of the network. If signal from far distant transmitters are delayed more than allowed by the guard interval they behave as noise like interfering signals rather than wanted signals. The strength of such signal depends on the propagation conditions, which will vary with time. The self interference of SFN for given transmitter spacing is reduced by selecting large guard interval. It should be note that the impact of delayed signal outside the guard interval may depend on receiver design. As an empirical rule, to successfully reduce self-interference to an acceptable value the guard interval time should be allow a radio signal to propagate over distance between two transmitters of the network.

Consider a receiver near the fringe of the coverage area of one transmitter. In general this receiver will pick up signals from several transmitters broadcasting the same programme. Although these signals are synchronized at the transmitters, they will reach the receiver with different delays. They cannot be distinguished from multi path signals, provided that the modulation is exactly the same. A modulation system is suitable for SFN operation if it can operate in conditions where a large excess delay is prevalent. If an SFN is based on existing transmitter separation distances, topographical obstacles will not produce larger excess delay than the signals of the various transmitters in the network. Signals from more–distant transmitters will exceed the maximum delay allowed for the OFDM signal. They will contribute only partly to the wanted field–strength and the greater the distance the greater will be the tendency for these signals to cause interference. However the network–generated self–interference of an SFN can be kept sufficiently low by careful choice of the system parameters and transmitter powers. If there are still some gaps in the coverage area of a network, they can be filled by additional low–power stations having the same frequency. In the case of terrain shielding, the same technique can be used as in conventional network planning, i.e. those regions can be covered by fill–in transmitters. If the necessary degree of isolation between the receiving and transmitting antennas can be achieved, the fill–in transmitter may work as a simple rebroadcast transmitter except that the transmitted frequency is the same as that received at the input, rather than having to transpose to a different frequency. If large buildings in urban areas provide the isolation, the “active reflector” technique may be of interest in such areas also. In principle the rebroadcast transmitter consists only of an amplifier the maximum gain of which is limited by the degree of isolation achieved between the anten nas. If there are differences in the programme or data content of the same service block, the advantages of the SFN concept are lost because of the resulting interference. In these circumstances the appropriate protection ratios must be observed.

There are two main methods of creating a single -frequency network. The first is through the use of on channel boosters. On channel boosters quickly receive the OTA signal from the main tower and retransmit the signal on the same frequency. The problem is that there is no error correction. So, any errors in reception are simply retransmitted along with the slight echo caused by the booster itself. On channel boosters are also limited in their placement as they need reliable reception from the main tower. With distributed transmission, the signal is delivered to each of its transmitters via fixed channels (land-based delivery). Then through the use of GPS -based reference clocks at each tower (for both time and frequency), the signals are synced so each can emit a perfe ct copy of both signal and symbol data. The result is a group of towers working in harmony.

No matter how synchronized the output from the towers may be, there will always be some amount of multi-path to deal with, and until recently receiver hardware wasn 't equipped to handle anything but very minor levels of multi-path. Multi-path as shown in Fig 1.2 is the result of your receiver seeing the same signal more than once. This can be caused by a variety of things. For instance, in a crowded downtown area the signal can bounce off buildings many times before it hits your antenna. The problem occurs when some copies of the data arrive more quickly than others. This, in effect, can jam your receiver.

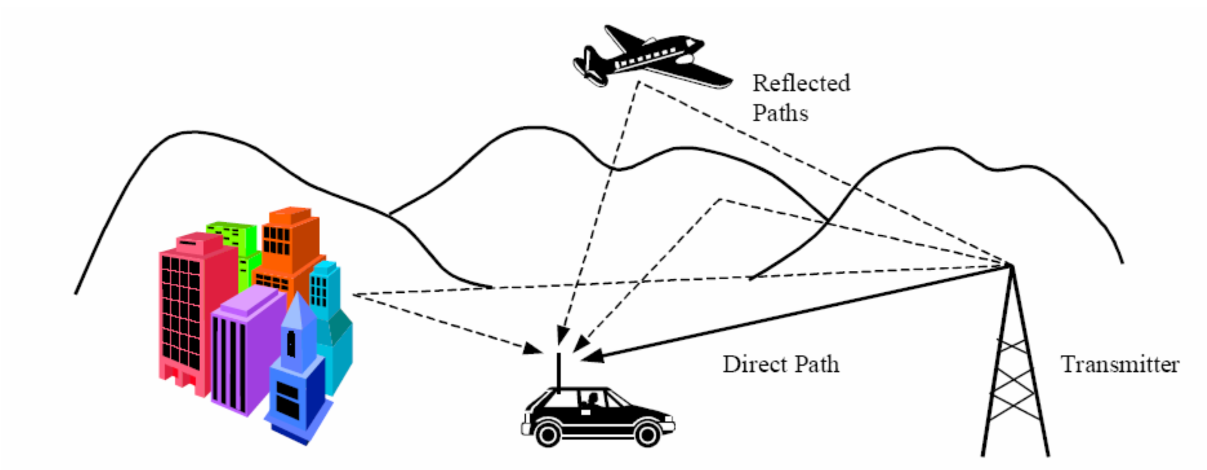

Fig 1.2 Multipath signals

The same effect occurs within SFNs. Because waves from different towers have the potential to reach your antenna at different times, a receiver's ability to handle multi -path is paramount to its success.

With that said, LG has continued to make great strides in their ability to hand le multi-path issues. Through the use of techniques such as adaptive equalizing they have even begun to turn a negative into a positive. First generation tuners had a multi -path window of -3 to +10 us. Fifth generation tuners have increased that window to -50 to +50. As always bigger numbers are way better.

This is not a new concept but is one has been used for many years on analogue medium wave networks especially in the UK and Spain. The opposite concept to a single frequency network (SFN) is a multi-frequency network (MFN) and a good example of this is RDS controlled analogue FM/VHF networks. In the OFDM world it may seem counter intuitive that an SFN can work better than an analogue equivalent. An SFN is created when all the transmitters in the network operate on the same nominal carrier frequency. The transmitters are designated as co -channel. In theory sub-carriers arriving from a transmitter outside the local service area can positively reinforce reception and replace a carrier lost through local anom alous propagation effects. With OFDM the transmitters have to radiate not just the same but an identical on air signal meaning that:

- The frequencies and phases of the sub -carriers have to be radiated to a very high tolerance.
- The individual sub-carrier frequencies have to appear at the same time.
- The individual sub-carriers have to carry the same data.

1.3 Frequency Efficiency:

With single frequency networks technique large areas can be served with common multiplex at common radio centre frequency. Therefore the frequency efficiency of SFNs appears to be very high compared to MFNs. However, taking into account the presence of similar network offering other programme multiplexes in adjacent areas, further radio frequency channels are required. The number of channels needed for international co -ordination is 4 at minimum; in practice 5 or 6 are realistic. Gap in the coverage area of SFN are easily filled by adding new transmitters without the need for additional frequencies.

1.4 Power Efficiency:

The SFN technique is not only frequency efficient but also power efficient. This can be explained by considering the strong local variations of field strength of any given transmitter. In conventionally planned networks and particularly in single transmitt er situation, a common way to achieve service continuity at high percentage of locations is include a relatively large fade margin in the link budget and thus to increase the transmitters power significantly. How ever with omni directional reception SFNs, where the wanted signal consist of several signal component from different transmitters the variation which are only weakly correlated, fades in the field strength of one transmitter may be filled by another transmitter. This averaging effect result s in smaller variation of the total field strength. Ac cordingly SFNs can use low powered transmitters. This power efficiency of SFN is important in the fringe area of a given transmitter and is often called "network gain". The benefit occurs only for reception o n low-gain, omni-directional antennas as are often associated with portable reception. Conventionally planned networks offer corresponding benefit only if the receiver is tuned to the frequency of the strongest signal after each change of location.

1.5 Synchronous Operation

The synchronous operation of all transmitters in a SFN does not preclude altering any part of modulation signal at any transmission with in the SFN, e.g to install local service inside the network. The difference in the modulation sign al causes the transmitter in question to turn to an interfere affecting the surrounding transmitters for duration of the signal difference.

2. Creating an Single Frequency Networks

To get each transmitter synchronized in both the time and frequency dom ains some extra data is added to the serial data streams (these contain the encoded audio and data inputs) the sent to the transmitters. This additional data stream is essentially a time reference signal inserted into the network. At each transmitter the O FDM modulator uses this time stamp to calculate the local delay so that a common on-air time is achieved.

SFN is a broadcasting network that utilizes the same frequency to cover their broadcasting service area. In an area where the radio waves from a TV tower (master station) become weak, a relay broadcasting station will re-transmit the broadcast wave to realize nationwide reception of TV program. Present analog broadcasting utilizes different channels for re -transmitting radio waves than that of the master station, to prevent interference between the relay stations and the master station. Digital terrestrial broadcasting will adopt the OFDM, which is resistant to such interference. It is able to realize single frequency networks (SFN) using the same chan nel for both the master station and any relay broadcasting stations.

Digital terrestrial broadcasting is scheduled to introduce this SFN system to effectively utilize broadcasting channels. Joint discussions by three parties, the Ministry of Public Managem ent, Home Affairs, Posts and Telecommunications (MPHPT), NHK, and commercial broadcasters, are underway. These concern channel assignments for a digital terrestrial broadcasting SFN system.

The advantages of the SFN approach are:

– High frequency efficiency;

– Low–power operation (internal network gain);

– High location probability;

– Easy gap–filling (frequency re–use).

The disadvantages are:

– Network splitting is not possible;

– Synchronization is necessary;

– Feed control is required.

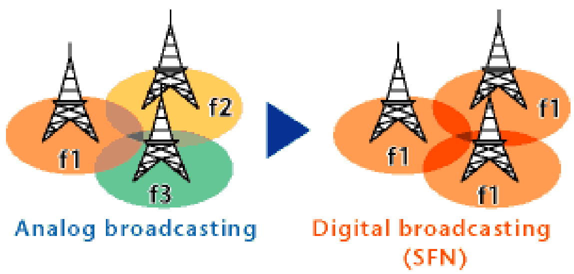

Fig 1.3

2.1 SFN Networks on DRM

Unlike line of sight networks that occur at Band III and Band IV/V implementing an SFN on short wave needs a little more thought. However Deutsche Welle in Germany has tested this system from two transmitters where one was located in Germany and the other in Portugal. DW decided on a control point in Germany (a designated geographical location) and then calculated the sign al transit time from Sines and Wertachtal via the ionosphere. Sines is the longer path so the signal from the Wertachtal transmitter was delayed by about 4 milliseconds to ensure that both signals arrived at the control point at the same time. The concept worked well as the signal decoded both before and after the SFN was in use.

RTL also tried to use the SFN concept using a transmitter in Julich, Germany and in Junglinster in Luxembourg. The control point was in France and even though reception was very good in the UK the signal did not decode at all.

In single frequency networks the signals coming from nearby transmitters are mixed since the interfering signals can be seen as long term echo's, an effective method to combat echo's such as OFDM is the natural candidate for SFN.

2.2 <u>Single Frequency Network Operations:</u>

SFN exclusive features are:

- Gap-filling possibilities
- Smaller frequency reuse distance
- Spectrum efficiency
- The right power at right place = power efficiency
- Smoother coverage
- Possibilities of tailoring / increasing the coverage area.

3. <u>OFDM (Orthogonal Frequency Division Multiplexing)</u>

Most of the research carried out about SFN is based on OFDM (Orthogonal Frequency Division Multiplexing). OFDM is indeed good candidate for SFN because of its power in reducing the effect of echo's. OFDM is a modulation technique for transmitting large amounts of digital data over a radio wave. W-OFDM stands for Wideband OFDM. The main proponent and inventor of W -OFDM is Wi-LAN of Calgary, Alberta.

Orthogonal Frequency Division Multiplexing (OFDM) is a Multi -carrier transmission technique, where the available spectrum divided into many carriers, each one modulated by a low rate data stream. OFDM is similar to FDMA in that the multiple user access is achieved by subdividing the available bandwidth into multiple channels, which are then allocated to users. However, OFDM uses the spectrum much more efficiently by spacing 22 the channels much closer together. This is achieved by making all the carriers orthogon al to one another, preventing interference between the closely spaced carriers. In FDMA each user is typically allocated a single channel, which is used to transmit all the user information. The bandwidth of each channel is typically 10 kHz -30 kHz for voice communications. However, the minimum required bandwidth for speech is only 3 kHz. To prevent interfering between channels, the bandwidth of each channel made wider than the minimum bandwidth required. This extra bandwidth is to allow for signals from nei ghbouring channels to be filtered out, and to allow for any drift in the centre frequency of the transmitter or receiver. The extra spacing between channels resulting in up to 40% wasted spectrum. This problem becomes worse as the channel bandwidth becomes narrower, and the frequency band increases.

TDMA partly overcomes this problem by using wider bandwidth channels, which are used by several users. Multiple users access the same channel by transmitting in their data in time slots. Thus, many low data rate users can be combined together to transmit in a single channel that has a bandwidth sufficient so that the spectrum can be used efficiently.

OFDM overcomes most of the problems with both FDMA and TDMA. OFDM divides the available

bandwidth into many narrow band channels (typically 100-8000). The carriers for each channel are made orthogonal to each other, allowing them to be spaced very close together. The orthogonality of the carriers means that each carrier has an integer number of cycles over a symbol pe riod. Due to this, the spectrum of each carrier has a null at the centre frequency of each of the other carriers in the system. This results in no interference between the carriers, allowing then to be spaced as close as theoretically possible. This overco mes the problem of overhead carrier spacing required in FDMA. Each carrier in an OFDM signal has a very narrow bandwidth (i.e. 1 kHz), thus the resulting symbol rate is low. This will give the signal a high tolerance to multipath delay spread, because the delay spread must be very long to cause significant inter -symbol interference.
In the mobile radio environment, signals are usually impaired by fading and multipath delay spread phenomenon. In such channel, severe fading of the signal amplitude and Inter -symbol interference lead to unacceptable degradation of the system error performance. It is expected that OFDM is capable of providing very high data rate with strong robustness of multipath delay spread, which make that Inter-symbol interference (ISI) is no longer a problem.

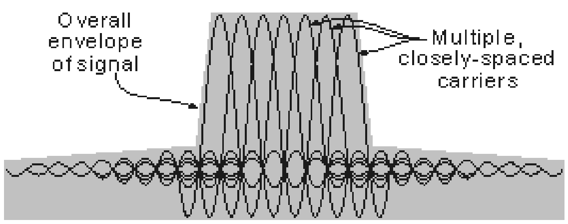

Fig:1.4 OFDM Spectrum

In recent years Orthogonal Frequency Division Multiplexing (OFDM) has gained a lot of inte rest in digital communication application. This has been due to its properties like high spectral efficiency and robustness to channel fading. Today OFDM is mainly used in digital audio broadcasting (DAB), digital video broadcasting (DVB), Wireless Local A rea Networks (WLAN), and other high speed data application for both wireless and wired communications.

3.1 Basics of OFDM

OFDM is especial case of Multi-carrier transmission, where a single data stream is transmitted over a number of lower rate sub-carrier. It is worth mention here that OFDM can be seen as either a modulation technique or a Multiplexing technique. One of the main reasons to use OFDM is to increase the robustness against frequency selective fading or narrowband interference. In single carrier system, a single fade or interference can cause the entire link to fail, but in Multi -carrier system, only a small percentage of the sub-carriers will be affected. Error correction coding can then be used to correct for the few erroneous sub-carriers. The concept of using parallel data transmission and frequency division Multiplexing was published in the mid 1960s [1]. In parallel data system, the total signal frequency band is divided into N non-overlapping frequency sub-channels. Each sub-channel is modulated with a separate symbol and then the N sub-channels are frequency Multiplexed. It seems good to avoid spectral overlap of channels to eliminate inter-channel interference. This lead to inefficient use of the available spectrum. To cope with the inefficiency, the idea proposed from the mid 1960s were to use parallel data and FDM with overlapping sub-channels, in which each carrying a signalling rate b is spaced b apart in frequency to avoid the use of high speed equalization and to combat impulsive noise and Multipath distortion, as well as to fully use the available bandwidth.

Figure 1.5 illustrates the difference between the conventional non-overlapping Multi-carrier technique and the overlapping Multi-carrier modulation technique. As can be seen from the figure 1.5 by using the overlapping Multi-carrier modulation technique , we save almost 50% of band with. In the 1980s , OFDM was studied for high speed modems, digital mobile communications, and high density recording. In 1990s, OFDM was exploited for wideband data communications over mobile radio FM channels, high bit rate digital subscriber lines (HDSL 1.6Mbps), asymmetric digital subscriber lines (ADSL up to 6Mbps), very high speed digital subscriber lines (VDSL 100Mbps), digital audio broadcasting (DAB), and high definition television (HDTV) terrestrial broadcasting.

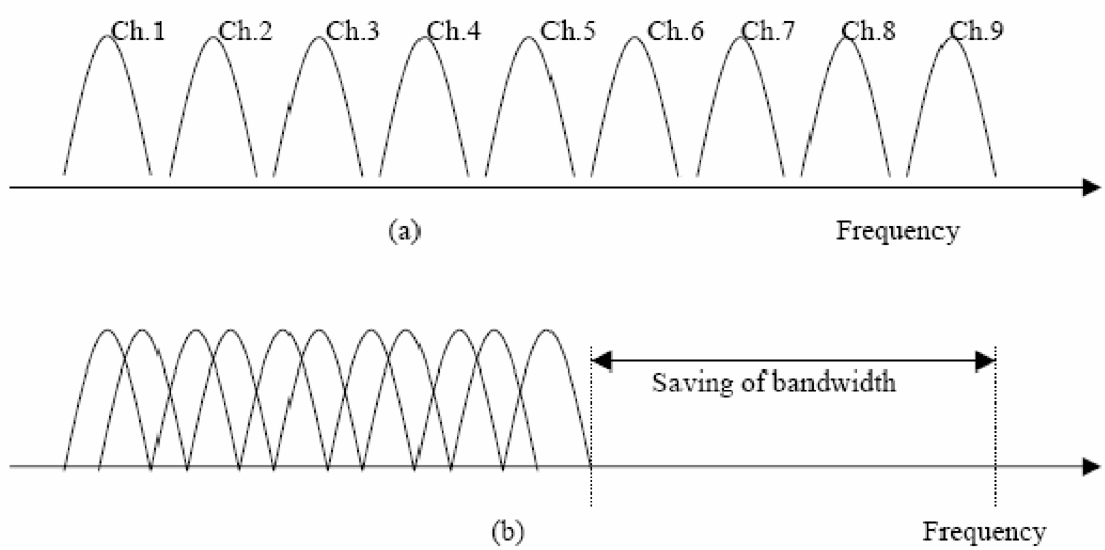

Fig 1.5 Concept of OFDM signal (a) Conventional Multi-carrier technique (b) orthogonal Multi-carrier modulation technique.

DAB/DVB networks are based on the Coded Orthogonal Frequency Division Multiplexing (COFDM) scheme [1, 2] that makes it possible to transmit the same digital information by many transmitters simultaneously using the same frequency band. This concept is often referred as Single Frequency Network (SFN). The introduced artificial multipath propagation is controlled by using long symbols as well as by inserting a guard interval betwe en consecutive symbols. Thus, a receiver can make use of several received copies of a signal, yielding potential diversity gain. However, signals with excessive delays create self-interference [4, 5]. Therefore, coverage design of SFNs focuses on planning the delay situation in the networks. There are several optimization techniques presented in the literature to cope with SFN planning for broadcasting services (see, e.g., [6, 7]). When many SFNs have to be designed simultaneously, frequency assignment to e ach SFN also becomes an important issue. Conventional broadcasting networks are characterized by unidirectional channels with unlimited user population per channel. However, the introduction of individual services presents a new constraint to the design: the finite capacity (bitrate) of an SFN is used as a shared resource by its users. The aggregated capacity demand from individual users establishes a lower bound on the number of SFNs. For a given service area, increasing the demand forces to use smaller SFN sizes and/or to use overlapping (overlay) SFNs, making the channel assignment problem even more difficult.

Now OFDM technique has been adopted as the new European DAB Standards and HDTV standard. OFDM is a candidate for the 4G mo bile communication. IEEE 802.20 as shown below is the application of OFDM.

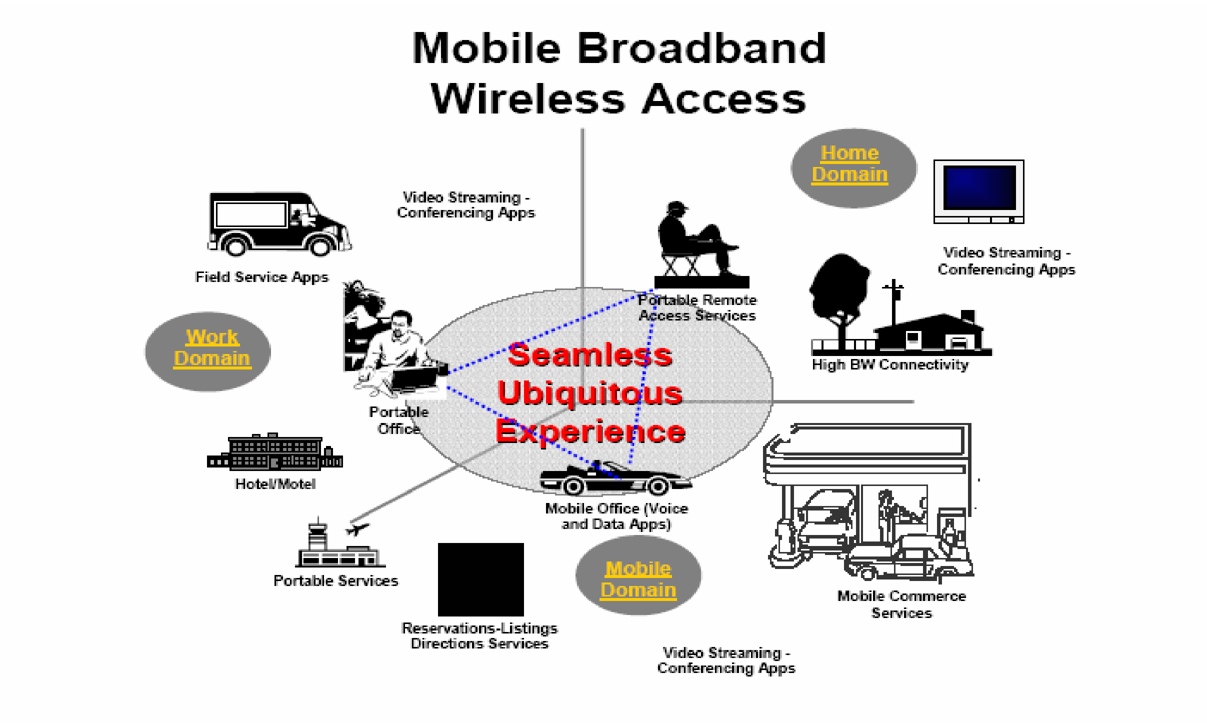

Fig:1.6 IEEE 802.20 as application of OFDM

The OFDM transmission scheme has the following advantages:

1- OFDM is an efficient way to deal with Multipath, for a given delay spread.

2- Using adaptive OFDM in slow time varying channels we can increase the capacity by adapting the data rate per sub-carrier according to the signal to noise ratio.

3- OFDM is robust against narrowband interference.

4- OFDM makes single frequency networks possible, which especially attractive for broadcasting applications.

On the other hand, OFDM also has some disadvantages:

1- OFDM is sensitive to frequency offset and phase noise.

2- OFDM has large peak to average power ratio, which reduce the power efficiency of the RF amplifier.

3.2 <u>OFDM Applications:</u>

a) DAB
b) DVB etc..

There are other applications also but we are restricting our self to DAB and DVB.

a) <u>Digital Audio Broadcasting (DAB)</u>

OFDM have been adopted by European standards bodies as the modulation choice for several variations of digital audio and digital television; for both terrestrial and satellite transmission. The European Digital Audio Broadcast (DAB) standard provides for three mode of operation.

Mode-1 is for terrestrial Single Frequency Network (SFN).

Mode-2 applies to conventional terrestrial local broadcasting.

Mode-3 is for satellite broadcasting.

DAB is a digital technology offering considerable advantages over today's FM radio, both to listeners and broad casting. DAB's flexibility will also provide a wider choice of programs, including many not available on FM. A single station might offer its listeners a choice of mono voice commentaries on three or four sporting events at the same time, and then combine the bit streams to provide high-quality sound for the concert which follows.

<u>Why SFNs are Possible with DAB:</u>

DAB is digital broadcasting system which was developed especially for the challenging transmission characteristics of the mobile radio channel. Typical phenomena of this channel like

Doppler shift and multipath propagation with resulting time and frequency selective fading had to be taken into account while developing DAB. To cope with these problems the guard interval was introduced between consecutive data symbols, time and frequency interleaving technique were applied to the data stream, a choice of sub carrier spacing in the multi -carrier modulation scheme was introduced and channel coding technique were applied to correct for transmission errors.

The DAB system is very robust and f requency economical transmission system which enables corrects decoding of information despite Doppler spread and multipath reception. The effect of multipath reception is depicted in Fig 1.7 both the directed signal from transmitter and reflected signal arrive at the antenna of the receiver.

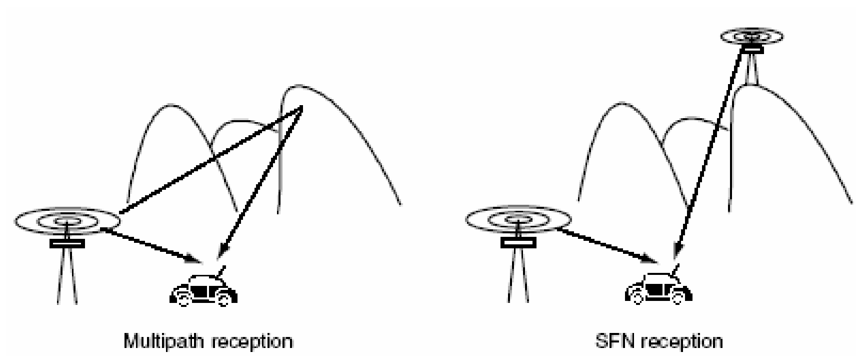

Fig 1.7

b) <u>Digital Video Broadcasting (DVB)</u>

Digital **V**ideo **B**roadcasting is an international digital television (DTV) standard that is the European and Far Eastern counterpart of the North American ATSC st andard. Administered by the DVB Project within the European Telecommunications Standards Institute (ETSI), DVB uses MPEG-2 for video compression and MPEG -2 and Dolby Digital for audio.

4. References

[1] European Telecommunication Standard Institute, "Radio broadcast systems; Digital Audio Broadcasting (DAB) to mobile, portable and fixed receivers," ETSI document, Draft prevision ETS 300 401, March 1994.

[2] European Telecommunication Standard Institute, "Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for digital Terrestrial television (DVB-T)," ETSI document, Final Draft pr ETS 300 744, November 1996.

[3] T. Lauterbach, and M. Unbehaun, "Multimedia Environment for Mobiles (MEMO) - Interactive Multimedia Services to Portable and Mobile Terminals," in ACTS Mobile Communication Summit, Aalborg, 1997.

[4] CCETT, "Analysis of Interfering Effects in a Single Frequency Network," CCETT GT V4/RSM 93, Sep. 1989.

[5] V. Mignone, A. Morello, and M. Visintin, "An Advanced Algorithm for Improving DVB-T Coverage in SFN," in Proc. International Broadcasting Convention, Sep. 1997.

[6] R. Beutler, "Optimization of Digital Single Frequency Networks," Frequenz, vol. 49, no. 11–12, Nov–Dec 1995.

[7] A. Ligeti, "On Coverage Optimization in Single Frequency Network for Digital Broadcasting using Simulated Annealing," in Proc. Nordic Radio Symposium, April 1995. .