Unlimited Mobile TV: Enabling Deep-Indoor and In-vehicle Reception of MDTV Using Antenna Diversity Technology

By Roy Oren, CTO, Siano Mobile Silicon

Abstract

Digital TV is expanding from home to everywhere - streets, cars, buses, trains, restaurants, the beach - as TV content consumption is changing from a stationary, satellite or tethered paradigm and a typical group viewing experience towards a more personal viewing experience on portable wireless devices.

The emerging world of mobile entertainment is being currently driven by the growing consumer demand for converged multi-media devices – and offering GPS services bundled with mobile digital TV capability is a primary example of this new trend.

The rise in popularity of in-vehicle mobile TV is not mutually exclusive to the rise in demand for unlimited stationery TV viewing. The mobile TV revolution born in Japan and Korea has seen huge consumer demand for blanket reception – a trend already evident in China and expected to emerge soon in Europe and beyond. Antenna diversity can not only solve the technology challenges faced by broadcasting MDTV to vehicles traveling at speeds, but also overcome reception difficulties of MDTV in deep in-door locations – another technology challenge for successful mobile TV roll-out. The paper addresses how antenna diversity can overcome what are arguably the two most problematic MDTV scenarios, deep-indoor and in-vehicle viewing - currently fueled by the consumer demand for anywhere, anytime television viewing.

The DVB-T challenge

Some of the currently available digital TV infrastructures, especially (Terrestrial Digital Video Broadcast) DVB-T in some countries in Europe, do not enable TV everywhere. Existing DVB-T deployments in Europe were intended for stationary reception using roof-top antennae and as such face issues due to impulse noises, below-roof antenna positions environmental disturbances, in-door coverage and of course, mobility. In addition, as long as analog TV (PAL) is still in service, the transmission power of DVB-T towers is limited, in order not to interfere with the analog broadcast.

Recent DVB-T receiver chips introduced to the market partially overcome these problems by introducing very high sensitivity and sophisticated mobility algorithms. Hence, outdoor reception of DVB-T over a mobile device is possible in almost every "covered" location in Europe.

Nevertheless, indoor reception – and especially "deep-indoor" (far away from any window) is more challenging, as the indoor signal strength is weaker, and there is no line-of-sight between the transmitter and the receiver, hence the radio signal bounces of various objects to get to the receiver (a phenomenon which is often referred as multi-path propagation).

In addition to DVB-T, initial CMMB coverage in China, which is in general better than that of DVB-T in Europe, still has some regions where reception is marginal.

How can indoor DTV reception be made part of the user experience everywhere?

Antenna diversity is a scheme that uses two or more antennas to improve the quality and reliability of a wireless link. The concept is already in use for technologies such as WiFi, wireless microphones, and others. For the DTV application the idea is to use the existing infrastructure and have several antennas inbuilt within the receiver which receive the transmission signal through different propagation paths. Thus, it becomes feasible to receive the DTV signal in spots where single antenna receivers fail to produce good user experience.

Processing Techniques

There exist several flavors of receiver antenna diversity, as described herein:

- **Switching** – In a switching scheme, the signal from only one antenna is fed to the receiver for as long as the quality of that signal remains above some prescribed threshold. If and when this signal degrades, another antenna is switched in. Switching is the easiest and least power consuming of the antenna diversity schemes, as it requires only a single receiver, but does not yield a significant improvement in reception.

- **Selecting** – As with switching, selection processing presents only one antenna's signal to the receiver at any given time. The antenna chosen, however, is based on the best signal-to-noise ratio (SNR) among the received signals. This requires that a pre-measurement takes place and that all antennas have established connections (at least during the SNR measurement), leading to a higher power requirement. The actual selection process can take place in between received packets of information. This ensures that a single antenna connection is maintained as much as possible. Switching can then take place on a symbol-by-symbol basis if necessary, with typical switching time periods of several milliseconds.

- **Combining** – In this scheme, all of the antennas continuously provide signal to the receiver, at all times. The signals are then "combined" and, depending on the sophistication of the system, can either be added directly (equal-gain combination - EGC) or weighted and added coherently (maximal ratio combination - MRC). Such a system provides the greatest resistance to fading, and thus the best performance, but since all the receive paths must remain energized; it also consumes the most power as it requires all receiving paths to be active all of the time.

Antenna diversity optimized for mobile TV reception

The scheme yields the highest performance and is therefore the most adequate for mobile TV, is MRC. In multi-carrier systems such as DVB-T, this scheme can even be further optimized as the weighted signal combination is performed on a carrier by carrier basis. For optimal performance each carrier is weighted according to its own signal to noise ratio (SNR). It can be shown that in such a system, assuming that, after channel equalization, the noise received in each of the paths is uncorrelated, the SNR in each of the combined carriers is the sum of the SNRs on each of the carriers from the different antennas.
In other words, if the SNR of carrier k in the receiver which is connected to the antenna is denoted as SNR_{kn}, then after weighted maximum ration combining, the SNR at carrier k would be:

$$SNR_k = \sum_n SNR_{kn}$$ (Summation over all the antennas)

There are several schemes to ensure non-correlation condition, i.e., to ensure that the noise, after channel equalization at the different paths is uncorrelated:

- **Spatial Diversity** – Spatial diversity employs multiple antennas, usually with identical characteristics, that are physically separated from one another. Depending upon the expected incidence of the incoming signal, usually a space at a fraction of a wavelength is sufficient (rule of thumb states that distance should be more than quarter of the wavelength). Note that, most MDTV systems use a UHF carrier frequency, as low as 470MHz. This implies that the effective distance between every two antenna in a diversity array must be at least 20-30cm to produce an effective solution. This scheme is most suited for MDTV technologies which use S-band (such as CMMB) where the wavelength is about 10 cm, and even at small devices one can fit several antennas distant a fraction of a wavelength apart.
- **Pattern Diversity** – Pattern diversity consists of two or more co-located antennas with different radiation patterns. This type of diversity makes use of directive antennas that are typically physically separated by a short distance. Collectively they are capable of discriminating a large portion of angle space and can provide a higher gain versus a single omni directional antenna.
- **Polarization Diversity** – Polarization diversity combines pairs of antennas with orthogonal polarizations (i.e. horizontal/vertical, ± slant 45°, Left-hand/Right-hand CP etc). Reflected signals can undergo polarization changes depending on the media. By pairing two complementary polarizations, this scheme can immunize a system from polarization mismatches that would otherwise cause signal fading.

Obviously, these schemes can be mixed. For example, two antennas can be located far away from each other, thus applying Spatial Diversity, but also positioned at a 90^0 angle from each other, thus applying Polarization Diversity as well.

The special challenge of indoor reception

Two main factors might degrade signal quality in indoor scenarios – weak signal and "blind spots", and antenna diversity has significant influence in both cases:

A. **Weak signal** – as current infrastructure does not employ gap-fillers inside buildings for DTV transmission, the signal level inside a building is often attenuated compared to the signal level outside the building. In this case the limiting factor is usually the intrinsic noise of the receiver. In a well designed receiver this noise will be a few dBs higher than the thermal noise. In order to be able to show smooth video, the signal level at the antenna output should be stronger than the noise floor by the minimal SNR required to receive the transmission, the minimum signal level which is required in order to show smooth video - called sensitivity. When using several receive paths, since the noise at each path is uncorrelated to the others, MRC simply means averaging the signals from the antennas, reducing the noise variance by a factor of N, hence diversity will increase the overall sensitivity of the receiver by $10*\log_{10}(N)$ [dB], where N is the number of antennas.

B. **Blind spots** – inside a room, where the receiver seldom has a line-of-sight view of the transmitter, it actually receives the signal through numerous reflections from various reflecting objects (neon bulbs, steel plates, people, walls, etc.) placed fairly close to the receiver. Reflections combine – interfere with each other - constructively or destructively, depending heavily on the exact location of the receiver. Usually in a room environment one can receive good signal at a certain spot, and when moving the receiver device by just a few centimeters the signal fades away. Another phenomenon is when the device is placed at a presumably ‘good' spot, but when people are moving around reflections pattern changes and a ‘good' spot suddenly becomes a blind spot.
Antenna diversity improves the reception quality as several antennas continuously receive the signal through different propagation paths, thus the chance of having a blind spot in all the antennas becomes negligible - usually two antennas will suffice to practically eliminate any blind spot.

Mobile Reception

Antenna diversity is not only necessary in addressing indoor MDTV challenges, but is a significant factor in enabling high-quality MDTV reception whilst traveling at speeds.

In addition to the problems mentioned above, there are several factors that might degrade the signal quality when the receiver is on the move:

A. **Selective fading** – A mobile channel usually consists of several reflections spanning a few micro seconds apart. When the area is covered by a few transmitters there are several clusters of these reflections, with the time gap between the clusters usually in the order of 10's of micro-seconds. While on the move each reflection phase and gain changes rapidly. This creates a phenomenon that can be observed in the frequency domain as "notches". The number of notches, their depth and their location changes from one symbol to another; the rate of change corresponds to the speed in which the receiver is traveling. Channel equalization compensates for the notches by introducing a gain on the attenuated carriers - by doing so it in affect increases the noise on those carriers. Thus, after channel equalization, the signal becomes flat across the different carriers, and the noise is at full range and has peaks in some specific frequencies. Depending on the number of notches and their depths, the average SNR across the carriers might degrade to the point where bursts of errors are imminent. As mentioned above, when using diversity, the SNR in each carrier is a sum of the SNRs on each of the carriers across the different paths. Since most of the noise in the mobile channel is contributed by faded carriers, and the probability that the same carrier will be faded at more than one antenna is low, the average gain in SNR is large - much more than 3dB. In fact, experiments conducted both in the lab and in the field show that the SNR gain in a two-path diversity receiver is 6-8dB. This means that, in a mobile environment, a diversity receiver can still show clear video when noise is stronger by 6-8 dB’s relative to a single antenna receiver.

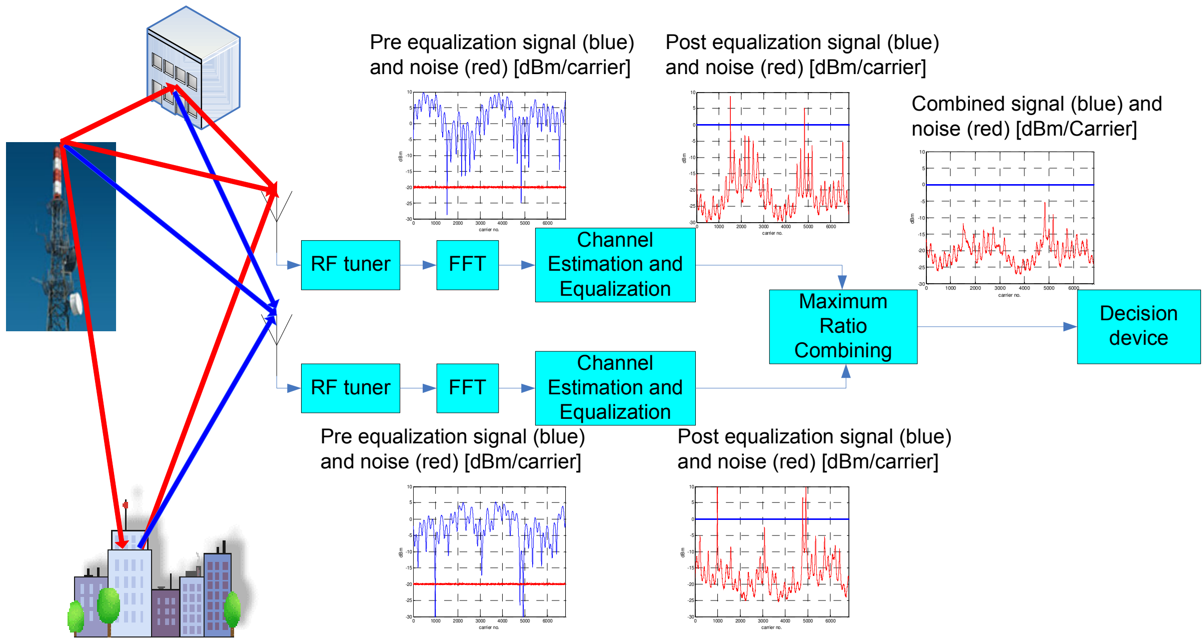

Figure 1: Combination of two paths with selective fading (mobile environment).

Each path had some notches which lead to negative SNR, after combination all the carriers have a positive SNR. Average SNR which is mostly influenced by the carriers with the strongest noise - is improved dramatically.

B. **Shadow fading** – A frequent phenomenon in the mobile channel is that of shadow fading, which occurs when close reflections combine destructively. When reflections which are distant less than (1/bandwidth) apart are of opposite phase, the whole signal will completely fade. This happens quite often when passing under a bridge, even at low speeds. A reflection from the bridge is a very close reflection and as such a destructive combination of this reflection with the main signal completely eliminates the signal. In some other wireless transmissions this issue is resolved by introducing long interleavers which in effect creates time diversity, but this is lacking in DVB-T as the interleaver spans about one millisecond. When placing more than one antenna, the phases of the reflections change and while in one of the antennas the signal combines destructively, it is bound to combine constructively in some of the other antennas.

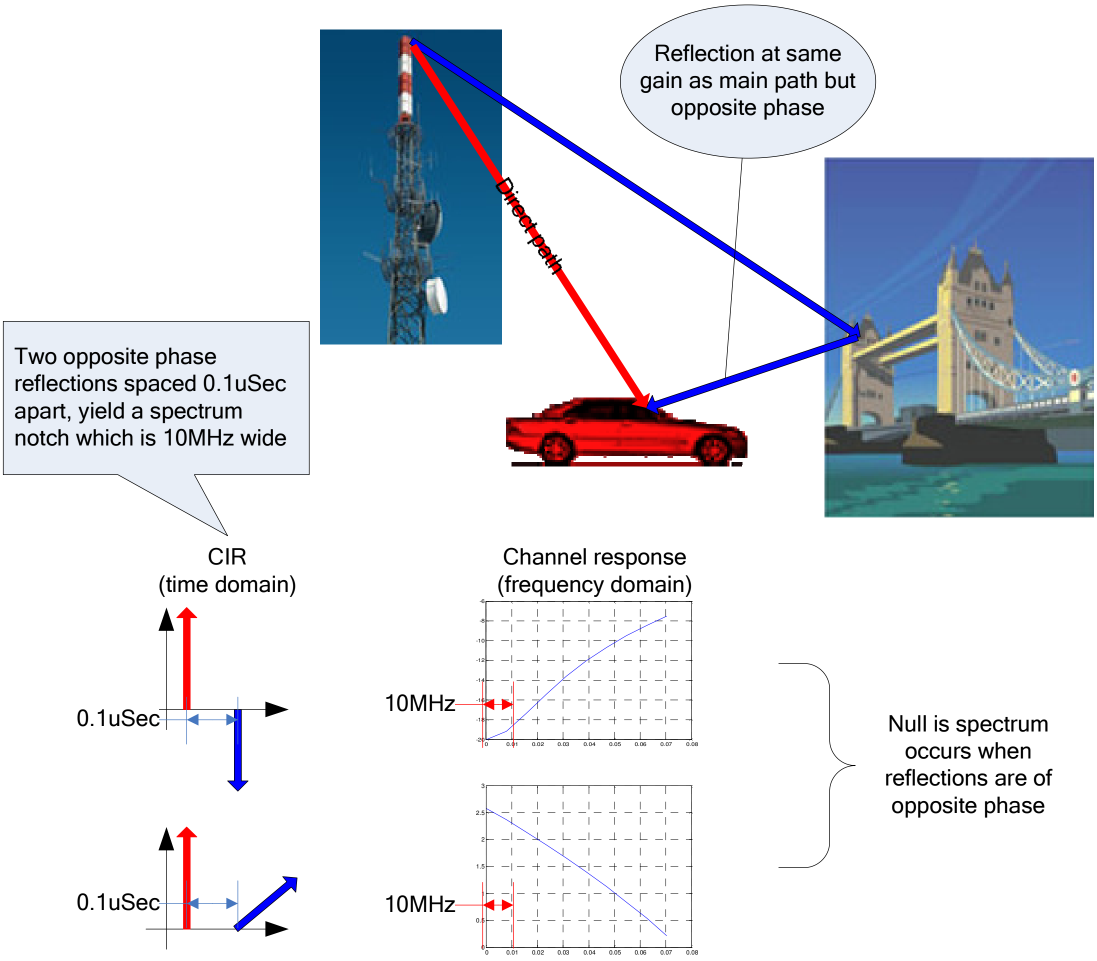

Figure 2: Driving towards a bridge example, the direct path and the reflection often combine destructively in a single antenna receiver

C. **Mobility** – When the receiver is traveling at higher speeds, channel variations during the symbol duration are no longer negligible. They result in Inter Carrier Interference (ICI), e.g., carriers are no longer orthogonal to each other, and energy from neighboring carriers leak to one another and creates noise. Another issue is the channel estimation which under these conditions becomes less accurate. These affects degrade the minimum SNR in which the receiver can still function. A diversity receiver which can still operate at lower SNR will not suffer from this effect, until it becomes very strong. Lab and field testing show that a two way diversity receiver will be able to function at more than twice the speed relative to a single antenna receiver! This is illustrated in

D. Figure 3 and Figure 4

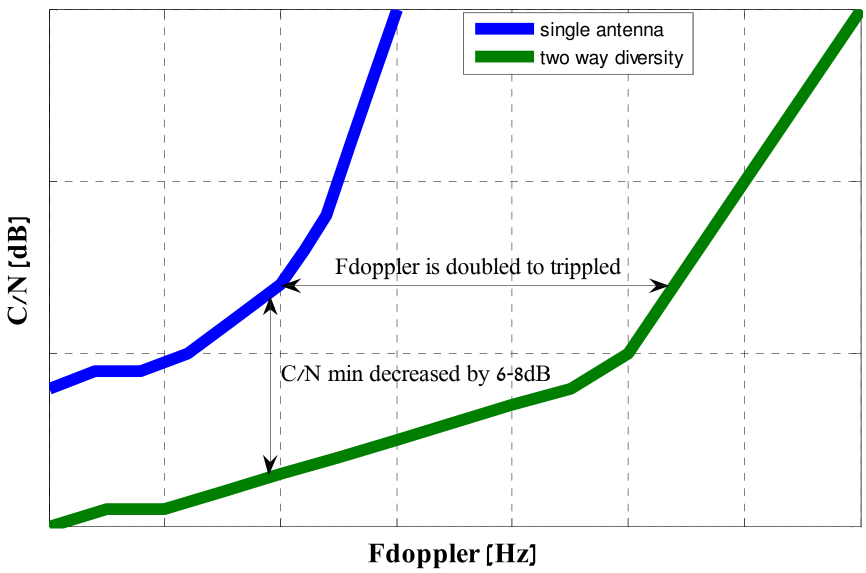

Figure 3: Min C/N vs Fdoppler qualitative graph

Figure 4: Reception while driving 120kmph, between Hannover and Braunschweig. Top picture shows reception quality when using single antenna receiver, bottom picture shows reception quality when using two antennas receiver. Similar impact was obtained in trials in China, with CMMB.

Implementation

The attractiveness of diversity in the case of consumer, battery-powered, mobile DTV devices depends on being able to meet some important commercial limitations. First, the overall power consumption of the receiver array must be sufficiently low to allow long-time viewing without having to re-charge the battery. Second, the small form-factor of most mobile devices implies strong size limitations. Third, in consumer devices price plays a major role in the decision making of the end user, thus the entire diversity solution must be cost effective.

Siano's SMS1240- based diversity solution offers extremely good sensitivity with noise figure of 3.5dB, and excellent mobility at a total power consumption of 200mW. In addition to DVB-T this solution also supports ISDB-T,T-DMB as well as FM Radio with RDS. This solution may be dynamically configured to enable viewing of two channels at the same time or a diversity receiver for a single DVB-T channel.

Figure 5: Siano's 4 way DVB-T diversity reference board based on 4 SMS1240 chips

Another example is Siano's 1180 which is a single chip solution to support CMMB two way diversity reception. This chip supports both UHF and S-band

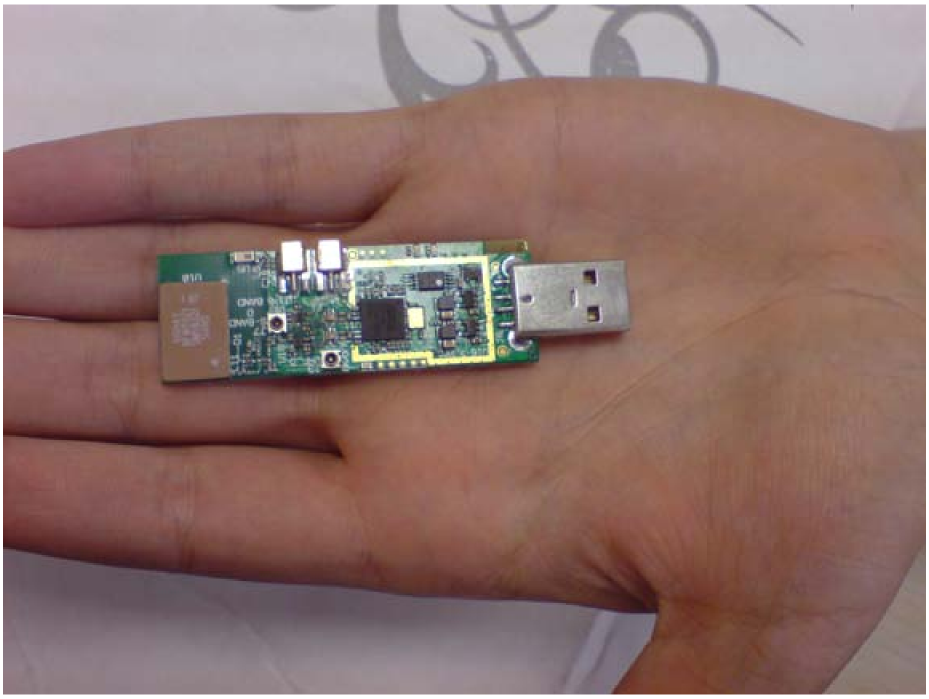

Figure 6: Diversity in a single chip using Siano's 1180 receiver

Conclusion

Antenna diversity represents the cornerstone for successful MDTV roll-out and consumer adoption. Strong signal reception will ultimately determine a good end-user experience – characterized by the adaptability and breadth of mobile TV enabled multi-media devices. Without antenna diversity – indoor reception and in-vehicle mobile TV viewing will not be of high enough performance to provide an uninterrupted high quality service, which ultimately underpins the very success of the anywhere, anytime mobile TV viewing experience. MRC techniques were shown to be effective both in Europe – with DVB-T, and in China, with CMMB.

About the Author

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Mr. Oren joined Siano in October 2004 and served as Architecture and Algorithms manager. He assumed his current position in October 2007. From 2000 to 2004 Mr. Oren held key engineering positions in Tioga Technologies - a fabless semiconductor company which was later acquired by STMicroelectronics - developing xDSL and broadband aggregation chips. As part of his responsibilities, he served as a systems expert in charge of system design for DSL product line, and managed a DSL development project. Mr. Oren also served as Algorithm team leader at Orckit Communications - a leading provider of digital subscriber line (DSL) solutions.

From 1994 to 2000, Mr. Oren served as an officer in the Israeli Defense Forces, where he developed and managed a wide range of high-technology projects in computing and telecommunications.

Mr. Oren holds a B.S.E.E Cum Laude from the Technion - Israel's Institute of Technology and an M.S.E.E from Tel Aviv University.