

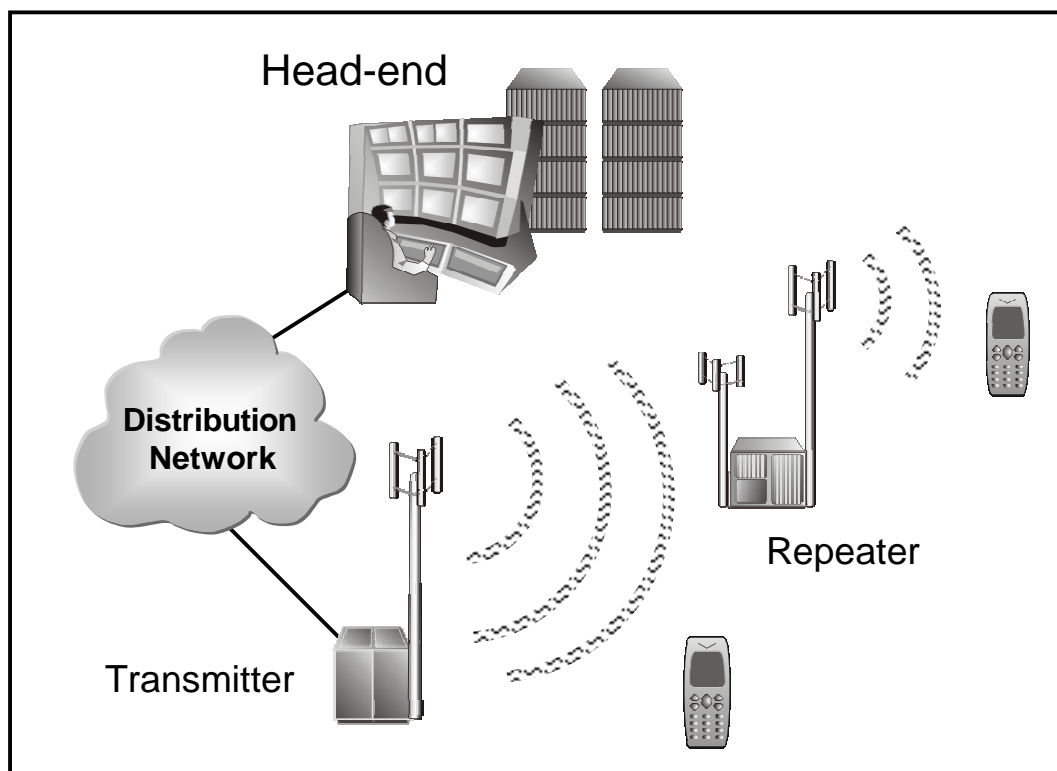
Transmitters and Repeaters as Digital and Mobile TV Gap Fillers

Digital TV network implementers have traditionally turned to repeaters for filling gaps in network coverage. New transmitter designs are changing the rules of the game and are becoming a compelling alternative, offering superior performance at a lower solution cost.

Transmitters

A transmitter performs in principle the same set of functions as a high-power broadcasting site:

- It receives, over a distribution network, the content for transmission from the network head-end
- It optionally performs program re-multiplexing according to location-specific requirements
- It modulates the output signal in compliance with the broadcasting technology in question
- In a Single Frequency Network (SFN), which requires tight signal timing coordination, it synchronizes its output signal based on GPS-timing and network signaling received from the head-end
- It power-amplifies the signal for output to the transmit antenna





Repeaters

Repeaters are signal emitters that are fed by a remote transmitter: they pick up the same digital or mobile TV signal that is directed at the end-customer receiver, amplify it and re-broadcast it towards more distant receivers.

A major concern with repeaters is output-input isolation: the input should be sufficiently isolated from the output signal, or else a positive feedback loop will be created and the repeater will cease to operate properly. Different types of repeaters handle this issue in different ways:

The simplest repeaters are used for in-building coverage: an outside antenna picks up the transmitter signal and it is then filtered and amplified for transmission inside the building. If the indoor transmitting antenna is sufficiently isolated from the outdoor receiving antenna, this simple scheme will work without creating feedback and oscillation of the entire chain.

Another type of repeater, which is not limited to indoor coverage, is a transposing repeater. In such a repeater the input signal is shifted in frequency to a different channel for transmission: with proper filtering, the frequency difference between output and input makes it possible to achieve the necessary isolation.

Some transposing repeaters are regenerative: they go beyond frequency translation and perform demodulation of the incoming signal followed by re-modulation on the out-going frequency. Regenerative repeaters thus achieve a higher quality output signal, at the expense of higher cost and longer processing delay.

An obvious limitation of transposing repeaters is that a second frequency channel needs to be available for their operation. In analog TV networks this was often feasible by re-using the frequency of another, sufficiently distant transmitter. Digital networks usually operate as SFNs, and a free channel is much harder to come by: therefore, they usually employ on-channel repeaters.

On-channel repeaters, as their name imply, transmit on the same channel they receive on. They do this, and can still be used for outdoor coverage, by employing echo-canceling technology that improves – up to a limit – input-output isolation. In an echo-canceling repeater, the input signal is first down-converted and digitized. The digitized signal is then operated on by an echo canceller that is similar in principle to the echo-cancellers used on long distance or VoIP telephone lines: a sample of the output signal is correlated with and then subtracted from the input signal in an attempt to cancel out the feedback path outside the repeater. Finally, the processed signal is converted back to analog, up-converted and amplified for transmission.

Note that on-channel repeaters cannot be regenerative – they cannot go through demodulation and re-modulation of the payload: operating within an SFN, the transit delay through the repeater needs to be as small as possible, and categorically smaller than the guard interval of the OFDM symbol. Regeneration will, clearly, introduce a much larger delay.

Transmitters vs. Repeaters

Traditionally, digital TV networks have been based on a relatively small number of high-power transmitters, with gap filling mostly being the domain of on-channel repeaters. New, small-footprint, integrated transmitters such as the Channelot 100 DVB-T/H Micro-Transmission Station or the Channelot 101 CMMB Micro-Transmission station are changing this equation by making a compelling case for gap filling by low-power transmitters.



Let us turn now to a more detailed discussion of the relative merits of transmitters and on-channel repeaters as digital TV gap fillers.

SFN Synchronization

An SFN transmitter using the timing signal of a co-located GPS receiver will easily achieve SFN synchronization with a timing error of less than 200 nS. An on-channel repeater will by necessity introduce a delay from its input – which is the output of the transmitter feeding it - to its own output. For state of the art repeaters, this delay is on the order of 5 μ S. While smaller than the typical guard interval, it will nevertheless mean that a receiver that is within coverage of both a transmitter and a repeater will see the latter as a significant-delay echo, degrading SFN performance.

Signal Quality

Modulation Error Ratio (MER) is the most common measure of digital TV signal quality. Transmitters, regardless of size, produce signals with the highest MER – typically better than 35 dB. Repeaters that are non-regenerative – including on-channel repeaters – introduce some degradation in signal quality: the MER of the output signal is at least 2 dB lower than that of the input signal, and is never higher than 34 dB even under ideal conditions. When some echoes are present and need to be cancelled – as is usually the case in realistic conditions – output MER is considerably lower: some repeaters will operate even in the presence of strong echoes that are higher power than the feeder signal; output MER, however, will be 25 dB or lower under these conditions – a level that will degrade the performance of 64QAM DVB-T.

Repeaters somewhat degrade the signal in other ways: for example, if the propagation channel from the transmitter to the repeater is not perfect, some frequency-selective distortion will already be present at the repeater input. The echo-canceller may assist in equalizing it, but some distortion is very likely to remain at the repeater output.

As another example, while the echo-canceller is well adapted to canceling low-delay echoes traveling directly from output to input, it cannot handle longer delay echoes that occur when the output signal bounces off a more distant object and is reflected back to the receiving antenna: long echoes will therefore not be cancelled and will add to output signal distortion.

Output Power

Even with echo-cancellation, isolation remains a limiting factor to repeater output power. For a given input power (determined by feeder-link calculation), the required level of isolation grows as a linear function of output power. However, there is a limit to the degree of physical isolation between output and input: antenna directivity, physical shielding and separation in distance are all practically limited by cost and site layout constraints. Finally, the echo canceller of a state of the art on-channel repeater will only improve isolation by 30-40 dB.

The upshot of all this is that the output power of on-channel repeaters is limited, even under the best of circumstances, to 10-30W. In contrast, transmitter output power is unlimited.

Site Selection

When selecting a transmission site, factors such as elevation, field of view, space, shelter, power etc are always a consideration. The placement of a repeater site is further constrained by the requirement that the repeater have a clear receiving path to the transmitter it is feeding off. Furthermore, a repeater should not be placed where its transmitting antenna is illuminating the receiving antenna of another repeater. The design of a repeater network needs to take these inter-dependencies into account, and the addition of a site may impact other, existing or future sites. In contrast, SFN transmitter site selection can be based on coverage considerations alone, and can be done independently of other sites.



Site Layout

A transmitter site needs to be laid out so its antenna has a clear field of view of the intended coverage area. A repeater site is more complex to implement: in addition to providing fields of view for both receiving and transmitting antennas, the two antennas need to be adequately separated and shielded from each other. This means that one roof-top spot will not do: use need to be made of, for example, opposite corners of the roof or points just below the roof. Those still need to be close enough together so that long cable runs do not cause excessive receive or transmit signal attenuation. Due to these constraints, a repeater site is much more difficult to procure and build out than a comparable transmitter site.

Coverage

Due to the required separation between receiving and transmitting antennas, repeater coverage is only practical if the transmitting antenna is sectoral and is pointing away from the feeder transmitter site. Therefore, an on-channel repeater needs to be placed at the edge of the desired coverage area, and within a specific section of the edge at that. This places even more constraints on site selection. Worse, it means that link calculation for repeater coverage needs to take into consideration a maximal range that is twice as large as a comparable transmitter, which could be placed in the center of the target area.

Urban coverage calculations most often use the Okumura or related Hata models. These predict that, for a typical gap-filler scenario, doubling the coverage range means twelve times the transmit EIRP. The repeater will employ a sectoral antenna that would typically provide a 5 dB gain advantage, but overall there is still a factor of four advantage for the transmitter: a 25W transmitter placed at the center of a given area will do the job of a 100W repeater placed at its edge.

Together with the limited output power available to repeaters as discussed above, this further restricts their performance envelope. All this is especially true for mobile TV, where a higher transmitter power is needed for building penetration and to compensate for the lower gain of the receiving antenna.

Signal Feed

Repeaters have the advantage of using, as signal source, the digital or mobile TV carrier that already exists to serve the end-user. Transmitters, on the other hand, need to be connected to a distribution (backhaul) network that provides them – out of band – with the content for transmission. The backhaul network is an additional cost element to gap filling by transmitters. However, there are many cases where this cost element is not significant or even relevant:

Signal distribution to the high-power transmitters is often done over satellite: satellite transmission is ideally suited to relatively high bandwidth, unidirectional, broadcast, one-to-many applications such as digital TV distribution: it's readily available at an overall low cost that is flat against the number of sites, and provides universal reach across almost any relevant geography. Once a satellite distribution network is in place, it is available to the gap filler transmitters at no additional cost.

Where satellite distribution is not used, an attractive alternative is presented by wireless backhaul: high-speed – 50 Mbps and above – unlicensed wireless links are readily available at a capital expense of 10% of that of a typical gap filler site, offering robust and operating-cost free transmitter connectivity. The added capital cost can easily be more than offset by the superior flexibility and output power provided by transmitters.



Equipment Complexity and Cost

Repeaters are sometimes perceived as simpler and more cost effective than transmitters, but this is not necessarily the case: the implementation of on-channel, echo-canceling repeaters involves down-conversion, digitization, signal processing, and then conversion back to analog, frequency translation and high power amplification – a chain that is just as complex as a transmitter's. If anything, echo canceling is less robust to implementation and propagation conditions than a transmitter.

A transmitter site does need to include, aside from the modulator (exciter) and HPA, a GPS receiver as well as a satellite receiver or backhaul network interface. Traditional implementations of these functions were indeed bulky and complex. However, the Channelot 100 (for DVB-T or DVB-H) and Channelot 101 (for CMMB) offer a fully integrated transmitter-site solution inside a single 2U box, and are superior to equivalent repeater products in their cost structure, footprint and ease of use.

Comparison Summary

Transmitters are superior to repeaters in signal quality, output power and flexibility in planning and deployment. The cost of transmitter backhaul is not a consideration when satellite transmission is already serving the high-power transmitters; in other circumstances, wireless backhaul presents an attractive alternative that, while adding a capital cost element, still maintains a superior overall solution. Finally, integrated transmitters such as the Channelot 100 or Channelot 101 are superior to on-channel repeaters in terms of cost and footprint.

Case Studies

RAI, Italy

RAI (Radiotelevisione Italiana) reported on a field trial of low-power transmitters as DVB-H gap-fillers. Pictured below is the coverage achieved by a 20W transmitter using a 40m-high omni-directional antenna in the city center of Turin:

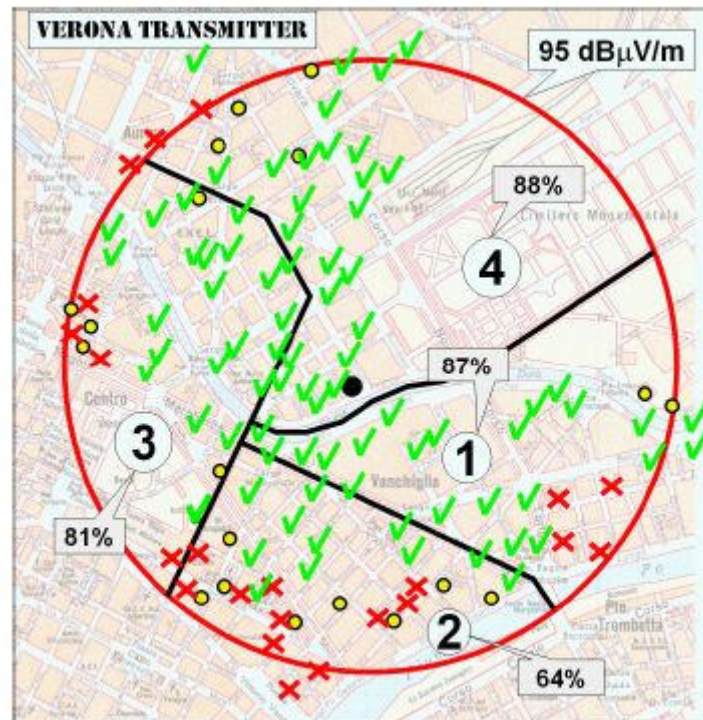


Figure 1: DVB-H Transmitter Coverage, Turin, Italy

This transmitter achieved an indoor coverage probability of 80% over an area within a radius of 2.5 km.

While the trial did not involve a repeater, several predictions can reliably be made on repeater performance under similar conditions:

As explained above, a repeater would have had to use a sectoral transmit antenna. A beam width of 90° with the same HPA power would have provided a 6 dB increase in EIRP. According to the Hata model for an urban environment, this would have increased coverage range by a factor of 1.5. However, the area covered by the repeater would still have been smaller by a factor of 1.8. Finally, the situation would have been even worse in reality: the choice of 20W for transmitter power was driven by the regulatory emission limit on the EIRP of an urban transmitting station. The same limit would have applied to a directional antenna, bringing the area covered by the repeater down to 1/4 of the transmitter's.

CMMB, using QPSK and a rate $\frac{1}{2}$ LDPC FEC, provides a 3 dB advantage in sensitivity over DVB-H. However, the comparative picture for CMMB would have remained the same, the only difference being an increase of 22% in coverage range for all scenarios.

Reliable predictions can also be made on indoor DVB-T coverage under similar conditions. Two factors need to be taken into account: on the one hand, DVB-T at 64 QAM raises the reception threshold (or the power required) by 16 dB relative to the DVB-H signal used in the trial. On the other hand, an indoor DVB-T antenna has a typical gain that is 7 dB higher than the mobile antenna's, and a further 5 dB gain can be assumed due to the fact that it is stationary and less obstructed.

Overall, then, the power budget for indoor DVB-T reception is 4 dB lower than DVB-H, translating to a range reduction by 25%. All other considerations, however, remain the same. (As a footnote, outdoor DVB-T reception would have been possible at a significantly higher



distance. Its calculation, however, calls for assumptions about large changes in link parameters, making the resulting predictions less reliable).

CNAB, China

CNAB Science and Technology Co. reported on a trial of on-channel repeaters in Hangzhou, Zhejiang province, China.

The trial took place in support of a mobile TV service to public transport vehicles. The red lines on the map mark major routes in the area along which reception is not possible due to shadowing from the main transmitter:

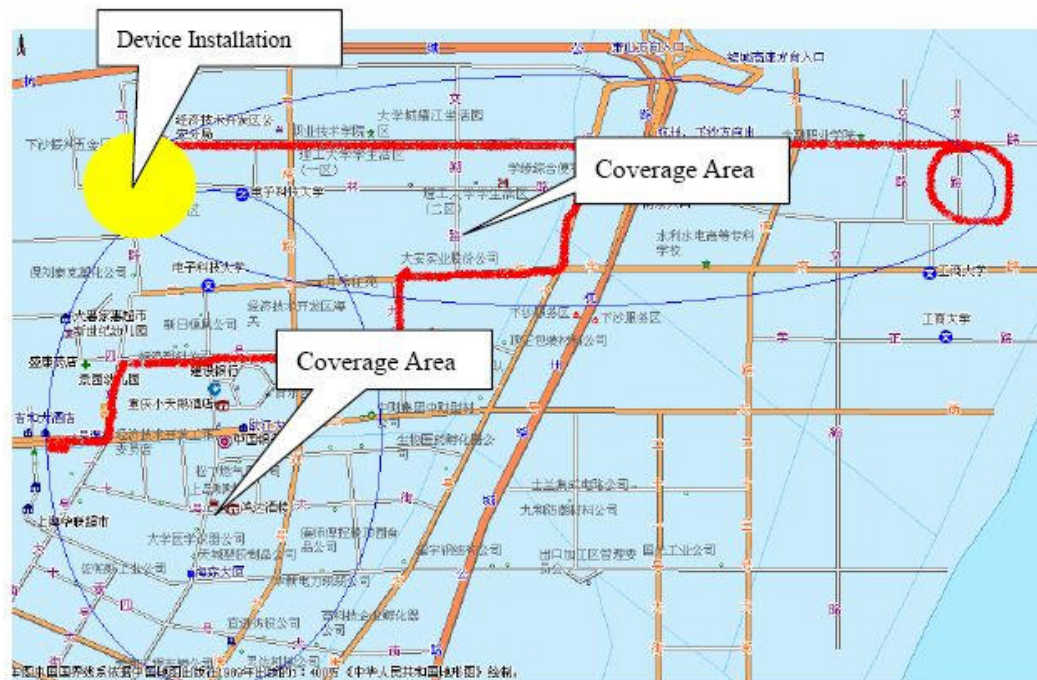


Figure 2: DVB-T Repeater Coverage, Hangzhou, China

The repeater site (marked by a yellow circle on the map) employed a 5W amplifier and was located at a height of 70m above ground. The distance from it to the eastern (rightmost) end of the coverage area was 5.5 km. Planning was done assuming a minimum receive signal level of 37 dB μ V.

The map clearly demonstrates the constraint of having to locate the repeater at the edge of the coverage area. The location of the high power transmitter is not reported but is clearly in the direction of the upper left corner of the map. Because of this choice of location, coverage was implemented by two antennas, each illuminating one of the ellipses marked in blue. Note that this leaves a gap in coverage at a section of the route near the center of the area. In contrast, a transmitter could have been placed where conditions are most favorable, probably closer to the center of the map, where it would have provided much better coverage and larger margins at the right and bottom left edges of the marked route (see more on transmitter power and signal strength below).



The repeater used in the trial had a processing delay of 5 μ S. While smaller than the guard interval of the OFDM symbol – 28 μ S – it does reduce it by close to 20%, leaving a correspondingly smaller margin to true multi-path signals.

The signal used in the trial was DVB-T with 16-QAM modulation and rate $\frac{1}{2}$ convolutional coding. The sensitivity of the vehicle mounted receiver was specified as –81 dBm. This information makes it possible to draw conclusions on the expected performance of in-home DVB-T and hand-held DVB-H under the same conditions:

The ITU Regional Radio Conferences of 2004 and 2006 (RRC-04/06) have published recommended planning factors for DVB-T network design. For portable indoor reception of DVB-T they have recommended a minimum field strength of 78 dB μ V/m – equivalent to a 51 dB μ V signal into a 0 dBi indoor antenna. This is 14 dB above the minimum signal level used for planning the trial, and means a repeater power of 125W would have been needed to provide indoor DVB-T coverage. This is clearly beyond the realistic output-power capabilities of on-channel repeaters. Even if it were not, it would significantly increase hardware cost and footprint. In contrast, a properly located transmitter would only need to deliver 30W of power. This is well within the capabilities of products such as the Channelot 100 or Channelot 101, and the savings in cost would more than offset the cost of wireless backhaul, if it were needed.

Indoor reception of DVB-H requires an even higher field strength: the power budget for DVB-H gains a 6 dB advantage in receiver sensitivity by using QPSK at a FEC rate of $\frac{1}{2}$. However, it loses 7 dB from the difference in antenna gains and an additional factor, estimated at 5 dB, due to mobility and obstruction. Overall, DVB-H therefore requires an additional 6 dB in field strength. This brings repeater and transmitter power to 500W and 125W, respectively, further highlighting the point of the comparison.

CMMB, by using QPSK modulation and a rate $\frac{1}{2}$ LDPC FEC, provides a 3 dB advantage in sensitivity over DVB-H. All other factors being equal, CMMB would therefore require half the transmit power of DVB-H. At 250W for the repeater, however, this is still prohibitively high, leaving the transmitter as the only feasible solution.

Conclusions

Filling coverage gaps in digital TV and mobile TV SFNs is more challenging than doing so for legacy analog networks. The traditional repeater-based solutions, therefore, fall short in many circumstances. Integrated, low-power transmitters combined with the right distribution network present an alternative that is superior in performance and lower in cost.