

Operational DVB-T SFN Experience in Australia

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Abstract

One of the touted benefits of the DVB-T standard has been the spectrum efficiency gained by employing Single Frequency Networks (SFNs). In order to provide sufficient DTV channels, the Australian Broadcasting Authority (ABA) identified coverage regions where SFNs must be employed. Under contract to the broadcaster the Australian Broadcasting Corporation (ABC), Broadcast Australia commissioned the first Single Frequency Network (SFN) during April 2002, in the Sunshine Coast region of Queensland. This satellite fed SFN had 5 transmitters covering 80 km in length. This paper examines the design and field experiences with the network as Broadcast Australia drew upon this experience to roll out further SFNs. BA now has 10 SFNs operational within Australia, one with 8 transmitters covering 240 km. These employ two different modulators and use satellite, ATM, fixed links and off-air feeds, sometimes with mixed feed types in the one network.

Introduction

Broadcast Australia, in conjunction with the ABA, conducted the first Australian trial of a DVB-T SFN in June 1999. The results of this trial (1) created a lot of interest in the use of SFNs in Australia. Subsequently, after wide industry consultation, the ABA determined that a number of coverage areas, including parts of major cities such as Sydney, Melbourne and Adelaide, were required to utilise SFNs to provide digital service coverage.

Broadcast Australia secured a number of transmission contracts with national broadcasters the ABC and the Special Broadcasting Service (SBS) to transmit their digital television programs. These included being responsible for the design and implementation of all the client SFNs. Broadcast Australia has now established SFNs on behalf of these clients in nine different regions.

SFN rollout and design

Network rollout

Broadcast Australia established its first SFN, for the ABC, during April 2002. At the time it comprised four sites in the Sunshine Coast area of Queensland. By the time of IBC 2003, a fifth site will have been completed to serve the township of Noosa. Experience with this network is detailed in this paper, and has been invaluable in assisting Broadcast Australia to understand SFNs further.

Since the establishment of the 1st SFN, Broadcast Australia has been involved in a continual program of building SFNs in other regions. As of IBC, SFNs for both the ABC and SBS have been established in: Queensland Sunshine Coast, Queensland Gold Coast, Sydney, New South Wales (NSW) Central Coast, NSW Illawarra, Newcastle, Canberra, Melbourne, Perth and Adelaide.

Network topologies employed

The SFNs planned and implemented by Broadcast Australia employ a number of different topologies and feed systems. The following table summarises the feed types and combinations employed in current SFNs.

Network feed type	Details
All satellite	Using QPSK SCPC carriers
All off air	Using DVB-T demodulators receiving a common main transmission (not part of the SFN)
Telco	ASI over ATM, via SDH microwave or direct Point-of-Presence (POP) ASI over IP via SDH microwave ASI over SDH fibre
Off air/Telco	Mixed feed types
Satellite/Telco	Mixed feed types

Table 1: Feed types employed by Broadcast Australia

Work before network establishment

SFN coverage planning

Broadcast Australia's experience in DAB SFN planning, beginning with trials work in 1995, has extended to designing DVB-T SFNs. Broadcast Australia uses a software package designed specifically for SFN planning. The ability to model receiver behaviour, view likely signal echo responses and produce a wide range of analyses are crucial to modelling SFN coverage as closely as possible.

Planning issues

Digital services are licensed in Australia so that SFN transmission sites generally:

- Are at predetermined locations (existing analog transmission sites).
- Use existing transmit antenna patterns and polarisation.
- Use fixed ERP levels as specified by the client broadcaster.
- Use the DVB-T transmission mode as required by the client broadcaster. (8k, 64QAM, 2/3 FEC, 1/8 GI for the SBS and 8k, 64QAM, 3/4 FEC, 1/16 GI for the ABC, both 7 MHz).

This means there is generally only one degree of freedom available to optimise SFN coverage and that is the relative SFN delay timing between each site.

Because of the restrictions in planning, especially the short guard intervals chosen, it has proven impossible to plan the SFNs so that all signals are within the

guard interval everywhere in the desired coverage area. Consequently, very rigorous planning has to be carried out to ensure that, even though interfering signals occur, that sufficient C/N is produced for the required target coverage availability. Therefore it is not good enough simply to determine whether or not signals are going to fall within the guard interval, as is the classical assumption with basic SFN planning. Indeed, it is a mistake to assume that a SFN can only work if all sites are located less than the guard interval away from each other.

Preparatory testing work for expected problems

From discussions with network operators overseas, it was clear that interoperability tests between different equipment/technologies need to be conducted before network establishment to ensure minimise problems at network start up.

Modulator interoperability

From the outset it was proposed that some SFNs would employ two different makes of modulators, because high and low power transmission equipment were sourced from different suppliers. Consequently, the two modulator types were set up in a benchtop SFN to compare processing times so that they could be synchronised together. Initially this was attempted by viewing the signals on the echo response of a DVB-T test receiver. However, due to difference in processing delays in the order of milliseconds, this proved impossible. After assistance from the manufacturers regarding likely processing delays, 'ball-park' figures were derived and the tests redone. This resulted in correction factors that needed to be applied to one make of modulator in order to synchronise it with the other. A different figure proved necessary for each modulation mode tested. Successful synchronisation between the two modulator types has now also been demonstrated in live networks.

Program feed transparency

The bit-synchronous requirement of SFNs mean that program feeds have to pass transport streams transparently, without any modification to packet order. Such a requirement is not necessary in ordinary multi-frequency networks. Consequently, as soon as each program feed type became available it was tested to ensure transparency.

This was checked by examining Megafame Initialisation Packet (MIP) errors as per ETR290 recommendations over a period of time. When this was conducted over the satellite distribution system for the first time, significant MIP errors were discovered, which prevented SFN operation. This was traced to random stuffing in ASI/45 Mbps G703 network adapters between the client studio and client satellite uplink, causing MIP (and other) packets to become dislocated. After the adapters were replaced with a type that marked then removed the added stuffing correctly, rather than randomly, the packet structure of the SFN transport stream was then correct and regular MIP errors disappeared.

Bitrate jitter

Bitrate jitter of program feeds of all kinds can have an impact into the stability of SFNs. It can lead to transmitted symbol clock jitter which can cause echo signals to 'wander'. The time varying spectrum can then affect consumer receivers depending

upon their implementation. Extremely large bitrate jitter is also a symptom of rapidly changing network delay, which may result in modulators being unable to track a delay change and cause transmission interruption. Consequently, as soon as appropriate feed types became available they were tested to examine bitrate jitter and general network delay stability.

The table below summarises short term overall TS Program Clock Reference (PCR) jitter and observations regarding network delay stability at typical SFN sites, using equipment employed in our networks.

Network Feed Type	Bitrate Jitter, 1Hz weighted	Network Delay Stability, typical delay
Satellite	Approx + -200nS	~250mS and stable
Off air	Approx + -750nS	~30mS through one 'hop' and stable
ATM over SDH microwave	up to + -200nS	~17mS through one switch and one hop and stable
IP over SDH microwave	up to + -200nS	~17mS through one switch and one link and stable
SDH optical fibre	Less than + -50nS	n/a

Table 2: Bit-rate jitter of program feed types

Certainly, field observations show that off-air fed networks do exhibit more wander than other feed types but has not caused any observable difficulties with set-top-boxes.

RF Combining difficulties due to SFN requirements

In Digital/analog combining networks, Broadcast Australia adopts the principle of offsetting the frequency of a digital service by +125 kHz if it is located on an upper adjacent channel to an existing analog service. This is to improve insertion loss and group delay of the analog channel sound carriers. Logically, since frequencies have to be the same in a SFN, then all common digital channels have to be similarly offset.

A positive offset of the SFN sometimes creates difficulty at other sites, when there is an analog service on an upper adjacent channel. Because it is not permitted to offset the analog channel by 125 kHz, site by site decisions have to be made: provide a separate antenna system at the original 'offending' site so that a positive offset of the SFN is not required; provide a separate antenna system at the site with upper adjacent analog so the digital does not have to combine with it, or; live with poorer return loss and channel rolloff at those sites in the SFN which then have a combined upper adjacent analog service.

Recommendations before a network is established

From Broadcast Australia's experience, the following actions are essential before an SFN is implemented:

- Sufficient SFN planning has to be conducted so that required site delay offset timings are known and any likely problem areas identified.

- Combiner chains/antenna systems have to be planned carefully with all infrastructure owners involved to identify any SFN offset issues.
- All program feeds should be tested for SFN compatibility.
- Different modulator types must be tested together if employed in the one network.

The Sunshine Coast ABC network in detail

Network description

The first SFN Broadcast Australia established used existing broadcast facilities at Bald Knob, Tozer Hill, Dulong Lookout and Black Mountain Radio Tower. This covers an area of approximately 80 km from north to south. The sites use ERPs in the range of 500 W to 15 kW on channel 62 with a frequency offset (centre frequency 767.625 MHz).

Headend equipment

Contractual arrangements with the client broadcasters are such that the required SFN head-end adapter and head-end GPS timing reference equipment are the responsibility of the client broadcaster, and are generally co-located with the multiplexing equipment. The SFN compatible transport stream, in this case, is then converted to a 45 Mbps G703 interface and carried across a SDH network to a satellite uplink facility. There, it is converted back to ASI and modulated using a QPSK SCPC satellite distribution system, at a nominal fixed bitrate of 23.052768 Mbps as is appropriate for the DVB-T transmission mode.

Transmission equipment

Because of the parameters of the satellite system, and high rainfall in the area, large 4.6 m satellite dishes were established at the sites. QPSK Signals were demodulated to ASI then fed to Digital Multimedia Technology (DMT) modulators and transmitters. At all sites RF signals were combined into a common antenna system with existing broadcasting services.

Frequency reference equipment

GPS reference systems were established at the sites to provide the required 10 MHz and 1 PPS signals for SFN use, with particular emphasis on stability, and availability of the signals. Since the establishment of the 1st network, the following issues have arisen concerning the use of GPS equipment:

- It can be difficult to ensure correct siting of GPS antenna systems to guarantee adequate reception at broadcast transmission sites. This is due to a lack of GPS measurement equipment generally available to ascertain reception quality.
- Careful attention has to be paid to the reaction of transmission equipment to short breaks in reference signals where GPS redundancy systems are employed.

Expected coverage

The expected coverage of the network, in terms of C/N margin above threshold, and the general distribution of the network is included as Figure 1 at the end of the paper.

Field work

Fieldwork was performed at a number of stages as time, and development of the network allowed. Before each stage, timing was checked at a number of reference points to confirm the network was still synchronised.

Measurement outline

Broadcast Australia's approach to SFN field work was to achieve the following outcomes:

- Verify correct SFN synchronisation and network timing
- Investigate performance in areas that planning identified as being marginal due to expected signal timing or level
- General coverage investigation to estimate whether coverage of the SFN matches that of the corresponding analog network it is intended to replace.

Measurements performed

The following measurements were generally performed at each measurement location using a DVB-T test receiver, set to 'SFN' channel equaliser mode:

- Terminal voltage/field strength using calibrated receive antenna system. A UHF phased array antenna was employed and a domestic Yagi for comparison at most locations. Digital planning in Australia assumes directional receive antenna systems.
- RMS Modulation Error Ratio (MER), extended to MER vs. carrier plots in later stages of fieldwork.
- RMS Signal to noise Ratio.
- Pre and post viterbi Bit Error Ratios (BER).
- Required Carrier to Noise (C/N) ratio to produce the Quasi Error Free (QEF) post viterbi BER of $2.0e-4$.
- Plots of echo and spectrum responses.

Indications were also recorded as to whether program decoding was reliable via the test decoder as well as using a typical Set Top Box (STB).

Problems encountered

During the course of the fieldwork a number of different, unexpected reception difficulties were encountered, caused by the following problems:

Drift of Transmitter Local Oscillator: Although the modulator remained locked to the GPS, at one site the final LO reverted to the internal reference, causing a slowly varying drift in the transmitted frequency. This manifested itself in an interesting way. At different measurement times at a particular location, either the measured MER/BER were poorer than expected for the given echo conditions but echo timing appeared correct and stable, or that expected echo timing was not correct (observed up to 10 μ S out) and MER/BER slightly poor. The latter is quite strange and at odds with expectation, as frequency offsets should result in spectral 'creep' or drift but should not affect echo timing as explained by Poole (2). It may have been caused by the equaliser action in the test receiver.

DVB-T test receivers are now available with external frequency reference facilities. This will help considerably with being able to determine the frequency accuracy of SFN transmissions during field work.

Modulator Bug Causing Complete Interference: When the network was extended from three sites to four, the fourth site could not be synchronised with the existing three. This was observed by lack of reception where it had been expected with very poor MER and lack of an observable echo. After further bench tests this was traced to a modulator bug which prevented correct transmission at certain delay offset settings. New firmware was quickly developed which solved the problem.

Incorrect modulator timing: Similar symptoms to the above, and MER vs. carrier response was 'lumpy' as the interfering signal was being received from the back of the receive antenna. This was caused by an accidental setting of a delay offset in a modulator to a wildly incorrect value during a firmware upgrade (120 mS rather than uS!)

Time varying interferer: At one particular site and time (dusk) pre viterbi BER was poorer than expected and MER v carrier response was varying in a 'bowing' pattern. This was thought, but not yet confirmed, to be caused by interference by another digital transmission on the same frequency over 100 km away during a time of abnormal propagation.

Pre-echo receiver performance: From the survey it was apparent that performance of both the test and the particular domestic receiver was not as good with pre-echoes as with post echoes. Reception was generally not reliable with pre-echoes approaching the guard interval. It was hoped by this stage of receiver development that implementation by the majority was nearing that promised by the nature of the COFDM system.

Test Receiver Equaliser performance: Under 'difficult' echo conditions it was observed that the MER of the two outer carriers was degraded, resulting in poor BER performance. In addition, nonsensical group delay plots were observed. The manufacturer confirmed that this was due to the limited ability of the channel equaliser to correct these carriers under difficult conditions. Different equaliser filters have to be employed for the outer carriers. This may be a problem that affects all practical receivers.

Network coverage

Figure 4 at the end of the paper includes the measurement locations and whether reception was reliable at each point using the test receiver. In summary, however, coverage of the Sunshine Coast network appeared to be close to that predicted, except for:

- A larger area of lack of reception than expected in Buderim, where obstruction of the nearest site resulted in out-of-guard band interference from the other sites. Analog reception in this area was also very poor. More topographic/clutter detail would have assisted in identifying this area during the planning process. It is unlikely that timing adjustment could alleviate the problems in this area.
- A couple of areas, north of Gympie and south of Noosa, where pre-echo performance of the receivers limited the coverage available.

Performance of the Sunshine Coast network may be able to be improved by readjusting site timing to reduce pre-echo delay, and by proposing another transmission site to serve the affected area of Buderim.

It was noted during the field work that the directionality of the receive antenna has, logically, a marked affect on the level of echoes and performance under difficult conditions.

Test receiver performance measurements

Under Gaussian conditions, and with the test receiver using the SFN equaliser setting, signal QEF threshold level for the transmission mode was approximately -76 dBm, which resulting in an apparent MER of ~19 dB.

Because of the outer carrier equaliser issues with the test receiver it was felt that the pre viterbi BER was a better figure of merit of reception difficulty than RMS MER. Figure 1 indicates the measured relationship between the two. There is strong correlation, as expected, except for those measurement locations where carrier specification problems were masked by the RMS measurement of the MER.

The Pre Viterbi BER is also sensitive to channel difficulty, as demonstrated in Figure 2. Together with the apparent stability of the measurement it is recommended that the Pre Viterbi BER be recorded with all field work, and also when evaluating transmitter performance.

To ascertain the reaction of the test receiver to echo level, sites were analysed which exhibited a single echo, with a delay lying in an assumed fairly linear area of operation of the receiver (from, say, 1/5 of the guard interval to 4/5). Figure 3 indicates the C/N required for QEF reception. The C/N has been corrected, removing assumed levels of Gaussian noise introduced by the receiver and transmitters. It shows the expected rise in required C/N as echo levels increase.

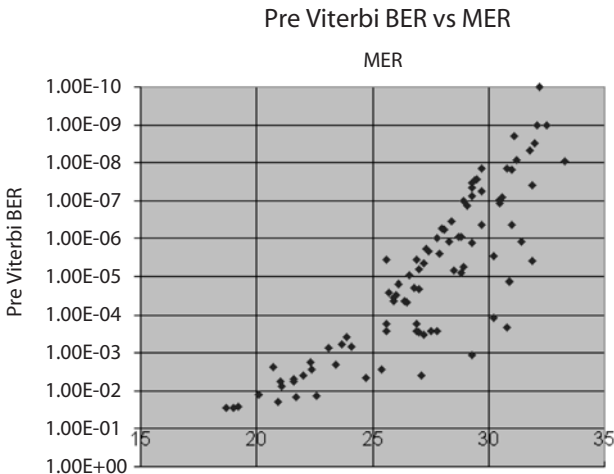


Figure 1: Pre-Viterbi BER vs MER

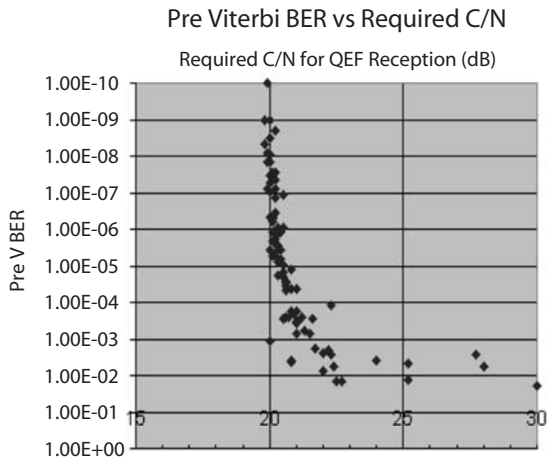


Figure 2: Pre-Viterbi BER vs Required C/N Ratio

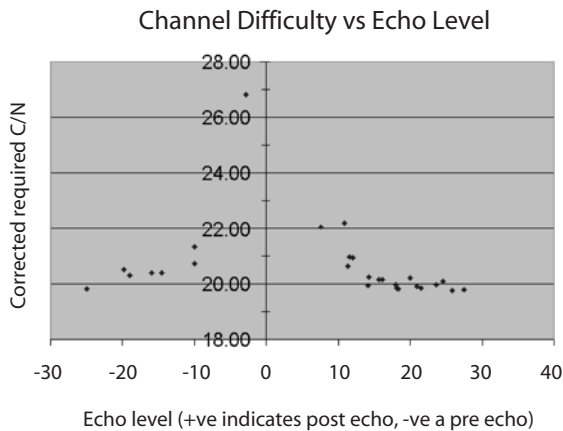


Figure 3: Estimate Channel Difficulty vs Echo Level

General conclusions from field work

The performance of the test receiver and the domestic receiver used were quite similar. Out of almost 100 measurement locations, there were only 5 locations where the domestic receiver was not able to gain reception where the test receiver could, and 4 locations where reception was possible with the domestic receiver but not possible with the test receiver. Consequently, performance measurements with the test receiver can give an accurate indication of possible reception in the general community.

From the problems encountered, it is clear that fieldwork should be conducted with as much knowledge as possible about what is to be expected in terms of coverage and the way a given receiver reacts to certain conditions. Often, network

problems can only be identified by the measurements not appearing quite 'right'. Unfortunately, it takes some time to build up experience with a device's reactions to various reception conditions.

The variation of performance with receive antenna type under difficult conditions highlights the need to choose the most appropriate type for each reception location.

Experience with other SFNs established

Other issues identified

From experience so far, the most difficult of feed types to use reliably are off-air reception. RF performance of commercial receivers, vagaries of propagation, interference and reliability of the main program transmissions all contribute to make it them a challenge. Currently, Broadcast Australia is still investigating why the program feed sites generate random RS errors, resulting in problems at the SFN sites. Indeed early on, the off-air receivers reacted to these by discarding the errored packets, creating MIP errors and shutting the SFN transmitters down. Firmware improvements to the receivers and the modulators have now reduced the impact to a very short glitch.

Future proposed field work

Broadcast Australia has started to embark on a field measurement program with the other networks now established. Particular attention will be paid to the performance of those networks using off-air or mixed program feed types, and a comparison of performance between networks of similar topology but employing the two different transmission modes.

Conclusions

Broadcast Australia's experience with SFNs has, so far, demonstrated that they are a practical means of conserving valuable spectrum whilst still providing sufficient transmission coverage. However, the following points are crucial to ensure that they are implemented as successfully as possible:

- Coverage planning has to be detailed and thorough, with accurate modelling of terrain, receivers and statistical processes.
- Planning in Australia assumes the use of directional receive antennas and indeed these must generally be employed to improve SFN reception with the short guard intervals used here. SFN reception may be difficult with omni-directional receiving antennas.
- Viewers may have to be prepared to change existing (i.e. analog) receive antennas and viewing patterns. The best direction for SFN reception may not be that currently used.
- Antenna installers need to be skilled and equipped with adequate equipment to be able to properly assess reception in a SFN environment.
- Receivers still need to improve pre-echo performance. Consequently, the Australian industry needs to embark upon examining, and sharing information about, the receivers available in the marketplace.

References

- 1 Iles, D.J., 2000. Large Area Single Frequency Networks: A Field Study into the Practical Applications. Proceedings of 1999 ABA Broadcast Planning Conference
- 2 Poole, R.H.M., 2003. Echoes, Doppler and DVB-R receivers: some theory and practice. BBC R&D White Paper WHP 054

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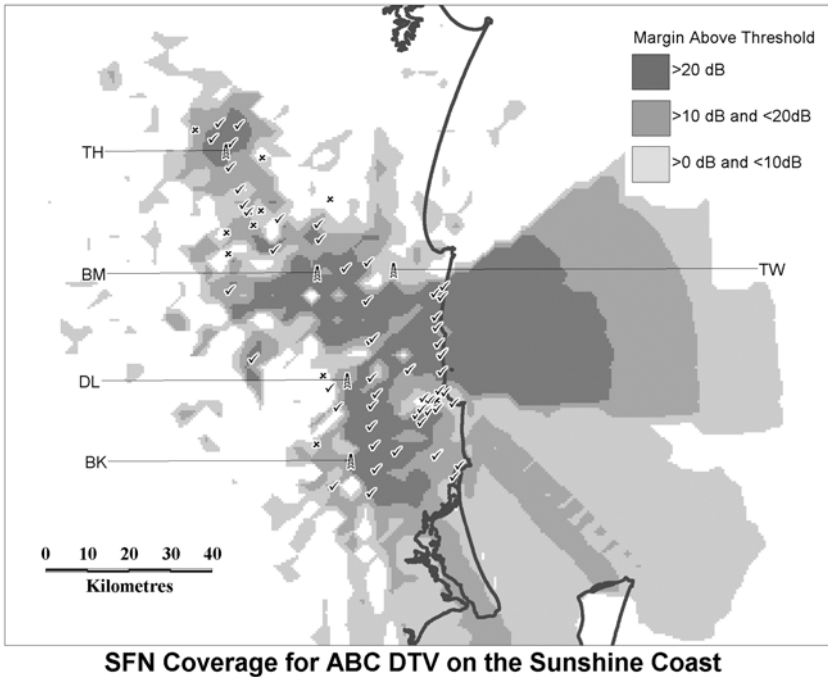


Figure 4: Predicted SFN coverage, with field measurement locations