TECHNOLOGY COMPARISON

Comparing Voice Coverage:
DMR and TETRA

CONTENTS

EXECUTIVE SUMMARY

This paper provides a technical comparison between DMR and TETRA voice coverage, providing a simple ratio between the number of base stations each requires to cover a given area. Both downlink (base station to terminals), and uplink (terminals to base station) paths are considered, across both urban and rural terrains.

It discusses the measurable factors affecting coverage, how they affect relative coverage between these two technologies and explains how the conclusions were reached. The measurable factors affecting coverage are:

- Link Budgets,
- Delay Spread,
- TDMA Guard Time.

Also relevant in real systems are terrain and external interference, but these factors cannot provide insight from a theoretical viewpoint. The many variables within terrain and external interference make comparing the coverage of different types of radio systems a very imprecise science. We can focus on the factors that are independent of these variables.

Coverage relating to voice operation only has been considered in this paper. Both DMR Tier 3 and TETRA Trunked networks require greater signal quality to set up the call than to maintain it, but that does not change the relative coverage ratios.

The analysis in this paper shows that for the downlink, for every DMR Tier 3 site, you need two TETRA sites to cover the same area. For the uplink, the ratio is even more in favour of DMR Tier 3:

- If the TETRA base stations have Receive diversity, every DMR site requires 2.5 TETRA sites.
- If the TETRA base stations do not have Receive diversity, every DMR Tier 3 site requires three TETRA sites.

These conclusions hold true for both urban and rural terrain.

While these conclusions are based on theoretical voice coverage science, research of real TETRA examples has shown universally that the results are even more weighted in favour of DMR.

The conclusions in this paper assume:

- the same site is communicating with a DMR terminal and a TETRA terminal that are side by side,
- the power outputs from the DMR and TETRA site transmitters are the same,
- the antenna systems are the same,
- neither system is simulcast.

TECHNOLOGIES AND CONCEPTS

This section provides an explanation of the technologies and concepts employed in this comparison, to provide more meaningful understanding of coverage design.

Both DMR Tier 3 and TETRA are digital trunked radio systems. They use advanced digital voice encoding and error correction techniques which effectively remove much of the noise reproduced on the audio output of Narrowband FM systems, maintaining voice quality almost to the edge of coverage.

DMR

DMR (Digital Mobile Radio) is a standardised system that complies with the common air interface defined in ETSI TS 102 361-1. It is two-slot TDMA (see below) operating in 12.5kHz channels, using four level frequency modulation (4FSK) at a data rate of 9.6kb/s.

DMR systems may be conventional (DMR Tier 2) or trunked (DMR Tier 3). The choice of conventional or trunked systems has different coverage implications which can be weighed against the benefits that trunked systems provide. This comparison is based on DMR Tier 3 (trunked) only.

TETRA

TETRA (Terrestrial Trunked Radio) is a standardised system that complies with the common air interface defined in ETSI 300 392 to 300 396. It is four-slot TDMA on 25kHz channels using linear π/4DQPSK modulation at 36kb/s data rate.

As the name implies, TETRA is trunked only - it has no conventional mode.

DAQ

With analog systems, received signal strength (RSSI) is a reasonable indication of audio quality. However, this is not always true for digital systems, so a new measure of audio quality was developed by the TIA to measure and compare audio, whether analog or digital.

Delivered Audio Quality is a qualitative measure of audio quality used to quantify the audio quality over a radio system. DAQ levels are defined by the following scale.

- DAQ 1: Unusable. Speech present but not understandable.
- DAQ 2: Speech understandable with considerable effort. Requires frequent repetition due to noise or distortion.
- DAQ 3: Speech understandable with slight effort. Requires occasional repetition due to noise or distortion.
- DAQ 3.4: Speech understandable without repetition. Some noise or distortion present.
- DAQ 4: Speech easily understandable. Little noise or distortion.
- DAQ 5: Perfect. No distortion or noise discernible.

SINAD and RSSI remain useful for analog systems; BER (Bit Error Rate) is common alongside DAQ.

TDMA

Both DMR and TETRA use Time Division, Multiple Access technology.

In a DMR system, each channel is divided into two time slots, each transmitting on the same RF frequency, but each capable of carrying a separate conversation. This means two radio terminals can transmit to (and from) the same base station; one on time slot 1, and one on time slot 2.

TETRA uses four-slot TDMA, which operates on the same principle, except that four radio terminals can transmit to (and from) the same base station; one on each of the four time slots.
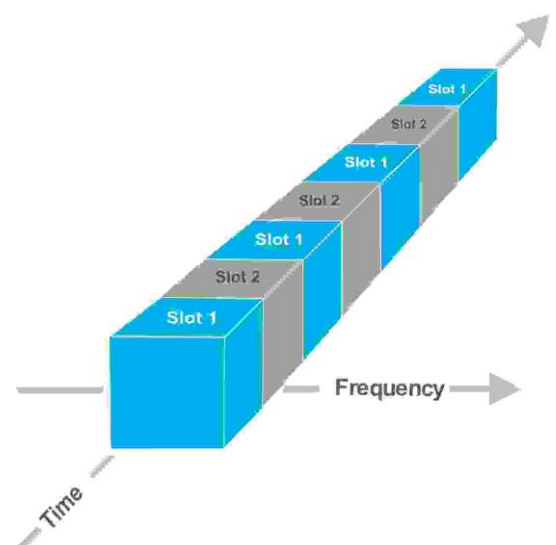
LINK BUDGETS

In its simplest form, a radio system consists of a transmitter, a receiver, operating over a channel. The link budget quantifies the performance of each, to provide a figure for the maximum possible path loss between the transmitter and receiver, for the link is to meet its performance objectives (eg: understandable received audio quality).

A typical **downlink** budget includes the base station Transmitter, mobile or portable terminal and the channel.

Base station/Transmitter

To determine the Transmitted Effective Radiated Power, (Tx ERP):

1. Quantify the transmitter output power.

2. Subtract the output power losses between the transmitter and the antenna associated with combining networks, cavity filters, duplexers and cable losses.

3. Add the specific gain from the transmitting antenna, which may be either omni-directional, or directional (radiates more efficiently in some directions than others).

From these figures, we arrive at:
Tx ERP (dBm) = Tx power (dBm) – Tx to Antenna Losses (dB) + Tx antenna gain (dBi)

Mobile/Portable Receiver

We need to consider the thermal noise floor of the receiver. Thermal noise is present at all frequencies - the wider the receiver bandwidth, the higher the thermal noise floor will be:

Receiver Thermal Noise Floor (dBm) = -174 + [10 * log (Band Width)]

The circuitry within the receiver raises the thermal noise floor. The total amount is the Noise Figure of the receiver.

- External interference raises the true noise floor of the receiver higher. (TIA TSB88.3-C contains some nominal noise floor values for different environments).

- Add the carrier-to-noise and interference ratio (Cf/(N+I)) for minimum acceptable link performance.

- Losses from cables between the receiver and antenna must be taken in to account, although these are usually small. Mobile receiver antennas are isotropic (omni-directional) so will have little gain; a portable antenna may even have significant loss.

Together, this gives us the minimum signal level required at the receive antenna, or Isotropic Receiver Level (IRL):

IRL (dBm) = Thermal Noise Floor (dBm) + External Noise Rise (dB) + Rx Noise Figure (dB) + Receiver to Antenna Cable Losses (dB) – Antenna Gain (dBi)

Channel

A link budget includes margins for Large Scale Fading (shadowing) and considers "clutter" (based on land use), building penetration loss, foliage loss and body loss. Examples of channel margins in a link budget might be:

Margin	Typical Figure
Large Scale Fading (Shadowing)	
Large City	12dB
Small City	10dB
Suburban	8dB
Rural	6dB
Foliage Loss	5dB
Body Loss	6dB
Building Penetration	10dB
Clutter (Land use)	6dB

Putting all this in to a diagram helps to illustrate link budgets more clearly:
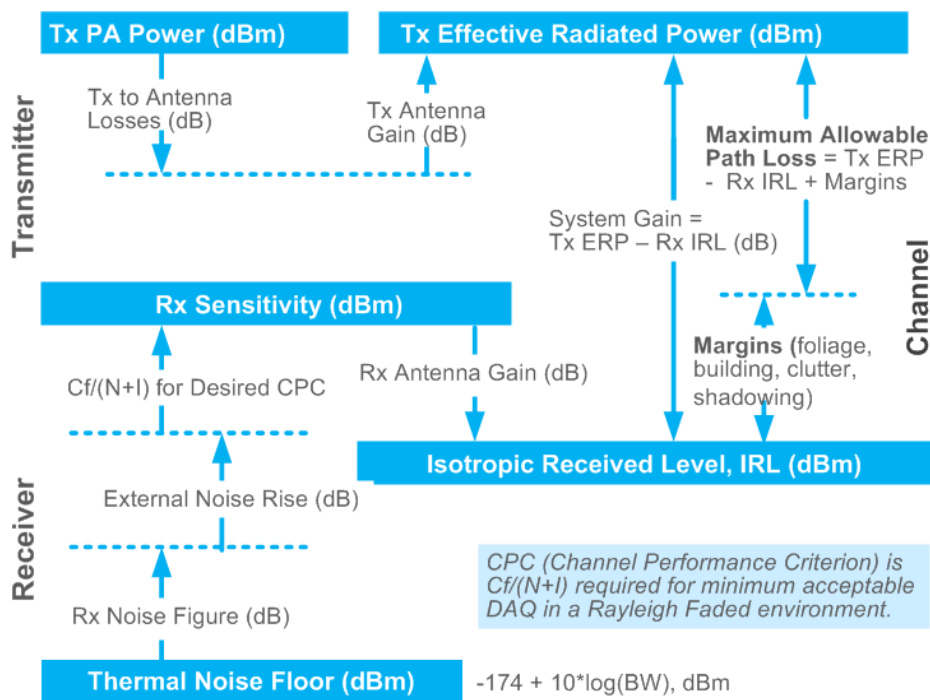
The Rayleigh fading margin is built in to the Cf/(N+I) figure at the Receive end of the link.
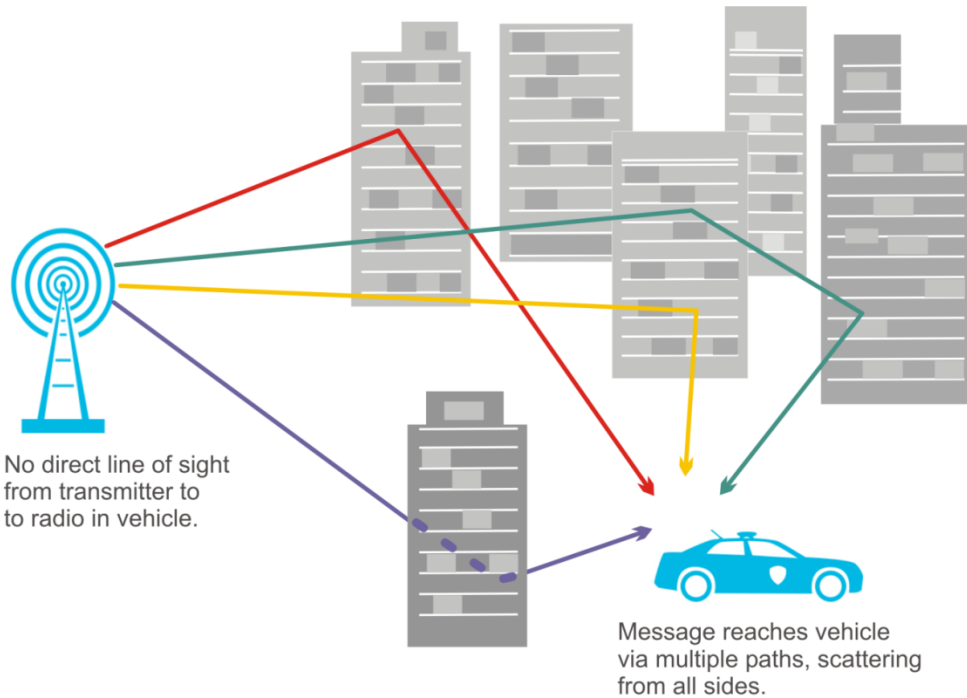
System Gain (dB) = Tx ERP – IRL
Maximum Allowable Path Loss (MAPL), dB = Tx ERP – IRL + Margins

DELAY SPREAD

A signal can travel from the transmitter to the receiver via many different paths, creating multiple copies of the signal. Because these copies travel different distances, they can arrive at slightly different times. The time difference between receiving the first multipath component of the signal, and the last is called Delay Spread.

If a signal is received at a given time, and a replica is received via a different path a fraction of a second later, the result is a 'blurring' of the information. If the delay spread becomes too great, the information cannot be understood – even if the signal level is well above the receiver's sensitivity level. This diagram illustrates the effect.

No direct line of sight from transmitter to to radio in vehicle.

Message reaches vehicle via multiple paths, scattering from all sides.

H E L L O	Small delay spread = imperfect, but understandable signal
HHH EEE LLLL LLLL OOOO	Some delay spread = degraded signal (still understandable)
H H H E E E L L L L O O O O	Large delay spread = confused, unintelligible signal

In the first line, the multipath components arrive at the receiver within a short time of one another. So, while there is some degradation, the information is still understandable. In the second line, the delay spread increases and it is harder to determine the information. In the third line, the delay spread exceeds the symbol time and the information is no longer understandable, so communication is lost.

For digital systems such as DMR and TETRA, the relevant figure is essentially two times the RMS delay spread. The tolerance to delay spread of a particular radio system is determined by the modulation used and the symbol rate (related to data rate) at which it is applied.

TECHNOLOGY COMPARISON

This comparison focuses on the three factors affecting coverage that can be measured from a theoretical perspective. These are:

- Delay Spread
- TDMA guard time.
- Link Budgets,

The following sections describe their relevance to coverage comparison between DMR and TETRA, how we make the comparison, and the conclusions reached.

DELAY SPREAD

DMR

DMR uses FSK based modulation (4FSK) modulation, meaning the transitions between consecutive symbols only involve changes in frequency. Hence the resulting signal is constant amplitude. There are four symbols (named +3, +1, -1, and -3) so each symbol conveys two bits of data. For DMR, the modulation is applied at a symbol rate is 4800 symbols/sec, giving a data rate of 9600bits/sec. The frequency shifts are either +/-648Hz or +/-1944Hz.
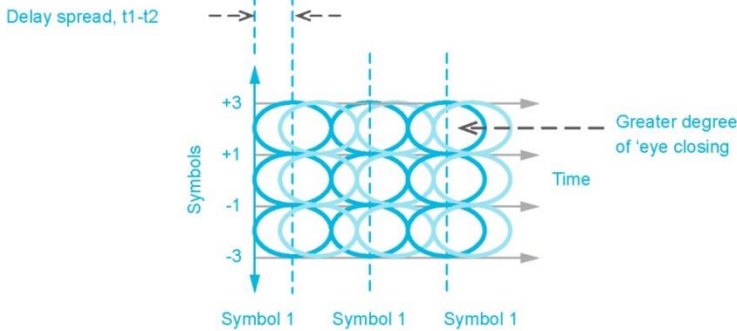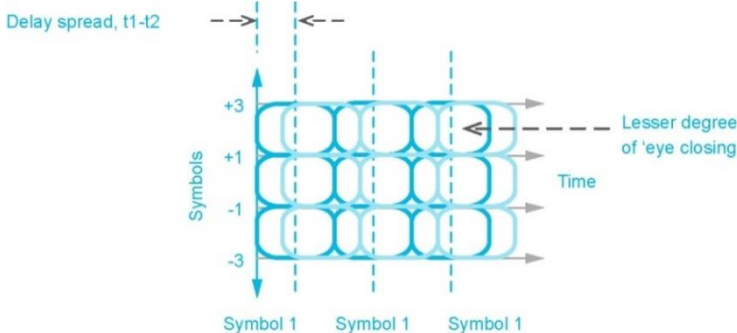

The diagram shows delay spread from multipath propagation. The received signal consists of multiple copies of the transmitted signal that have travelled different paths and arrived at different times. The elliptical eye diagram means that, in the presence of delay spread, the eye 'closes' quite quickly to the point where the BER degrades to 2% (DAQ3.4).

So DMR 4FSK modulation is not very resilient to delay spread. At 9.6kb/s data rate, maximum tolerated delay spread for DAQ3.4 is around 28us (13% of symbol time).

TETRA

TETRA uses π/4DQPSK modulation, a type of Differential Quadrature Phase Shift Keying, where symbols are separated by differences in phase. Four symbols (+3, +1, -1, and -3), each convey two bits of data. TETRA modulation has a symbol rate is 18000 symbols/sec, so data rate is 36000bits/sec. Transitions between consecutive symbols involve both changes in amplitude and phase, so the resulting signal is non-constant amplitude.


TETRA modulation is much more tolerant to delay spread than DMR 4-FSK, and the data rate is nearly four times faster. So the maximum delay spread that can be tolerated for DAQ3.4 is around 15us (27% of the symbol time).

The diagram shows delay spread resulting from multipath propagation - multiple copies of the transmitted signal that arrived at different times. The more open π/4DQPSK eye diagram means it is quite resilient to delay spread:

Note that, for a given symbol rate, PSK-based modulations (like TETRA's π/4DQPSK) are spectrally "cleaner", but require linearized transmitters because the transition between symbols involves signal amplitude change.
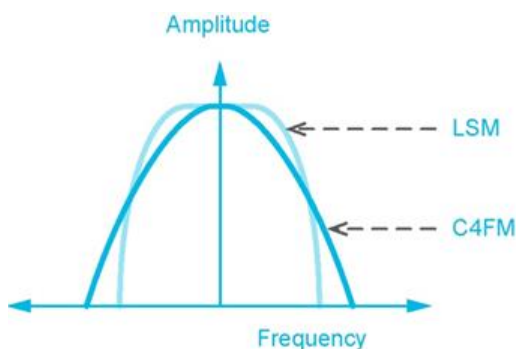
For the same symbol rate, FSK-based modulations (like DMR's 4FSK) produce more energy in adjacent channels. However, because the transition between symbols involves only a frequency shift (the amplitude stays constant), a simple non-linear FM transmitter can be used successfully.

A comparison of the typical transmitted spectrum of π/4DQPSK and 4FSK is shown on the left.

PSK-based modulations can achieve a greater data rate (bits per second) inside a given channel bandwidth. So in the 25kHz channel bandwidth used by TETRA, π/4DQPSK modulation can be applied at a rate of 18000 symbols/sec. Even allowing for the fact DMR operates in 12.5kHz channels, it can only achieve 4800 symbols/sec before the power generated in the adjacent channel becomes prohibitive.

Another trade-off is the efficiency of the transmitters required for π/4DQPSK and 4FSK. As 4FSK is constant amplitude, DMR employs standard class AB (nonlinear) FM transmitter with efficiency around 65%. On the other hand, for TETRA, the π/4DQPSK signal also contains amplitude content, hence a linearized transmitter is necessary. There are many linear PA architectures, but these are all more complicated and have much lower efficiency.

TDMA GUARD TIME

DMR TDMA means two radio terminals can transmit to (and from) the same base station at the same time; one on Time Slot 1, and one on Time Slot 2. For TETRA, four radio terminals can transmit to (and from) the same base station.
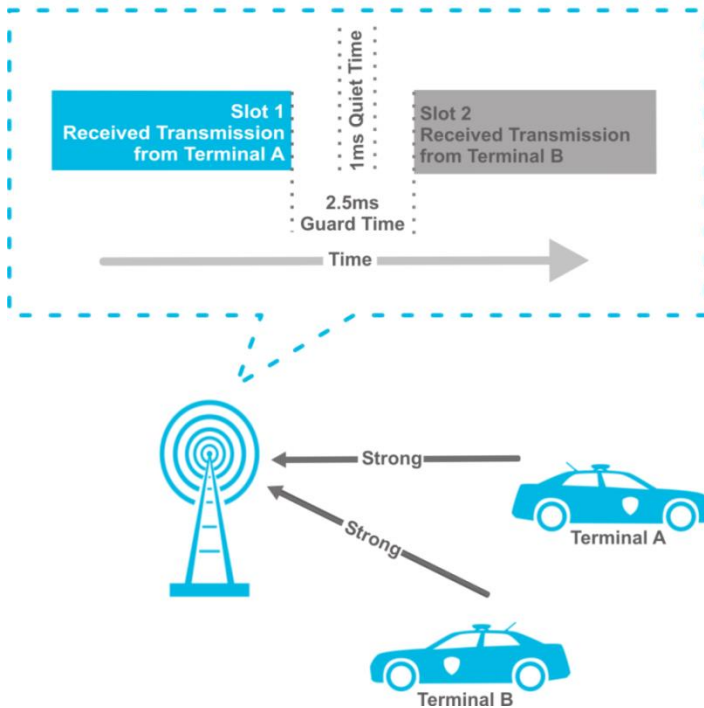

To prevent interference between the two time slots, guard time of 2.5ms separates the transmissions, to compensate for transmission timing differences when one terminal is transmitting much closer to the base station than the other. Interference can occur when the end of one transmission overlaps with the start of another, due to timing differences.

Guard time between TDMA slots for DMR is 2.5ms, but once transmitter ramp up and ramp down times are subtracted, the actual quiet time between the slots is 1ms. If two terminals are the same distance from the base station/receiver, we see the full guard time between receiving the two transmissions:

However, if one radio is further away from the base station, the propagation delay (the time taken for the transmissions to reach the base station) is longer. The radios' DSP clock frequencies may be slightly different, so respective transmissions can start slightly earlier or later than ideal.)

If one radio keeps travelling away from the base station, propagation delays eventually mean the base station would receive the back end of the transmission from Terminal A at the same time as the transmission from Terminal B began:

Because the signal from terminal transmitter A is stronger, due to its proximity to the base station, the end of the transmission from terminal B would be lost.
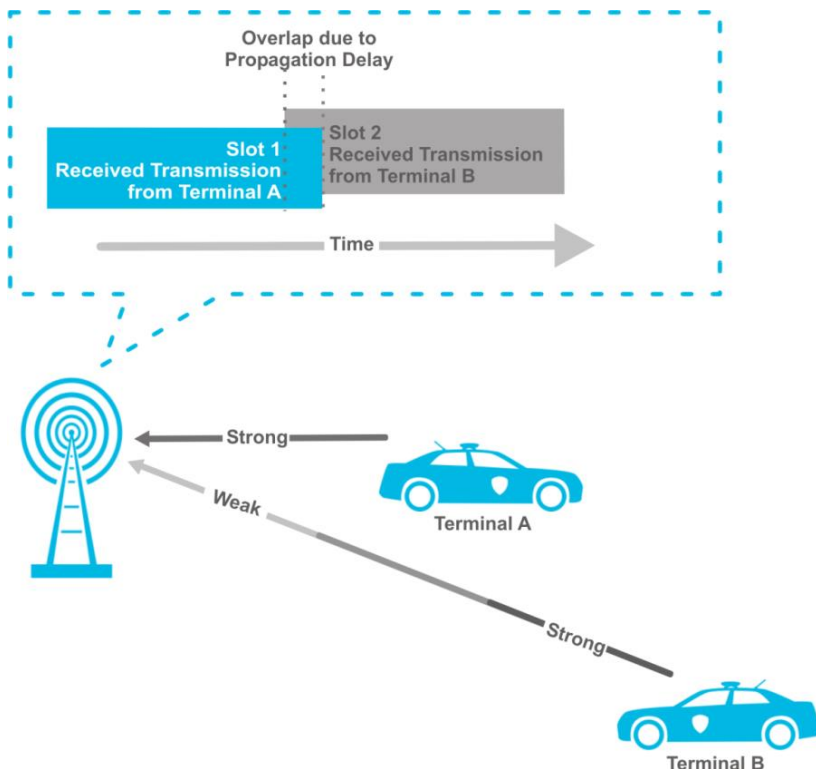
This issue is the TDMA Near/Far problem and can be easily addressed. TDMA guard time determines maximum coverage for a system with uniform distribution of radios, so the longer the guard time, the greater the base station coverage radius will be.

TDMA GUARD TIME - DMR

Between the 30ms TDMA slots is a guard time of 2.5ms. Due to transmitter ramp down and ramp up, Of this, only 1ms is truly 'quiet' so that is what we should consider.

TDMA guard time and the terminals' clock accuracy can be used to calculate the theoretical DMR coverage boundary. Guard time effectively accounts for propagation delays resulting from the greater distance between Terminal B and the base station receiver.

Signal speed is (3×10^8 m/s), so in 1ms the signal travels:

Distance = 3×10^8 m/s * 1ms = 300km

Tait DMR terminals have 0.5ppm clock accuracy, which this can cause transmissions from the system terminals to start slightly earlier or later than they ideally should, ie:

- 0.5ppm error leads to 0.5us delta over 1 second.
- In the DMR standard, the calculation for coverage boundary uses a transmission time of 125seconds (very few terminals can transmit continuously for that long, but that is what the standard uses).
- In 125seconds, a terminal with 0.5ppm clock (ie: 0.5us drift per second) drifts by 125 x 0.5us = 0.0625ms
- Now, picture that one terminal could drift 0.0625ms one way (eg: advance) and the other terminal could drift 0.0625ms the other way (eg: retard).
- So, 0.5ppm clock can result in 2 x 0.0625ms = 0.125ms total drift.

What this means is we actually don't have the full 1ms available to account for propagation delays; we really have 0.125ms less than that, ie: 0.875ms. So to repeat the previous calculation, in 0.875ms the signal travels:

Distance = 3×10^8 m/s * 0.875ms = 262.5km

In practice, this number is halved to account for uplink (Terminals to base station in this case) and the downlink (ie: communication in the other direction, from base station to Terminal), giving us a theoretical coverage boundary of 131.25km

TDMA Guard time - TETRA

We can do the same calculation to work out the theoretical coverage boundary for TETRA, where there is a guard time of 0.4ms between the TDMA slots.

The guard time is effectively available to account for the propagation delays resulting from the distance between terminal transmitter B and the base station receiver. If we take the speed of the signal (3×10^8 m/s), then in 0.4ms the signal travels:

Distance = 3×10^8 m/s * 0.4ms = 120km

If we assume that TETRA terminals have the same 0.5ppm clock accuracy as Tait DMR terminals, and also assume the continuous transmission time is 125ms, then drift due to these can cause the transmissions from the system terminals to start slightly earlier or later than they ideally should, ie:

- 0.5ppm error leads to 0.5us delta over 1 second.
- Let us assume TETRA uses a continuous transmission time of 125seconds, as per DMR.
- In 125seconds, a terminal with 0.5ppm clock (ie: 0.5us drift per second) drifts by 125 x 0.5us = 0.0625ms
- Now, picture that one terminal could drift 0.0625ms one way (eg: advance) and the other terminal could drift 0.0625ms the other way (eg: retard).
- So, 0.5ppm clock can result in 2 x 0.0625ms = **0.125ms** total drift.

This means we don't have the full 0.4ms available to account for propagation delays; we have 0.125ms less than that - 0.275ms. So to repeat the previous calculation, in 0.875ms the signal travels:

Distance = 3×10^8 m/s * 0.275ms = 82.5km

In practice, this number is halved to account for uplink (terminals to base station in this case) and the downlink (communication in the other direction, from base station to terminal), giving us a theoretical coverage boundary of 41.25km.

LINK BUDGETS

The link budget quantifies the transmitter, receiver and channel properties, and results in a figure for the maximum acceptable path loss between the transmitter and receiver for the link to meet its performance objective (eg: understandable received audio quality). The following are example downlink and uplink budgets for DMR and TETRA.

DMR

DMR Link Budgets for Urban Terrain - Parameters	Downlink	Uplink Mobile	Uplink Portable
Transmitter:			
Output Power (dBm)	See note	44	36
Transmitter to Antenna Losses (dB)	See note	0	0
Antenna Gain (dBi)	See note	0	0
Effective Radiated Power, ERP (dBm)	44	44	36
Antenna Height Above Ground (m)	50	1.5	1.5
Channel Margins:			
Large Scale Fading (Shadowing) for 95% reliability	8	8	8
Other Losses (Foliage, Building Penetration, Clutter)	10	10	10
Receiver:			
Bandwidth (kHz)	8	8	8
Noise Figure (dB)	8	8	8
Dynamic Cf/(N+I) for DAQ3.4	15	15	15
Antenna Gain (dBi)	0	0	0
Antenna Height Above Ground (m)	1.5	50	50
Dynamic Sensitivity (dBm)	-112	-112	-112
Link Budget	138dB	138dB	130dB

Note: the base station Transmitter ERP is assumed to be limited to 25W (+44dBm) by regulation.

DMR Link Budgets for Rural Terrain - Parameters	Downlink	Uplink Mobile	Uplink Portable
Transmitter:			
Output Power (dBm)	See note	44	36
Transmitter to Antenna Losses (dB)	See note	0	0
Antenna Gain (dBi)	See note	0	0
Effective Radiated Power, ERP (dBm)	44	44	36
Antenna Height Above Ground (m)	30	1.5	1.5
Channel Margins:			
Large Scale Fading (Shadowing) for 95% reliability	6	6	6
Other Losses (Foliage, Building Penetration, Clutter)	5	5	5
Receiver:			
Bandwidth (kHz)	8	8	8
Noise Figure (dB)	8	8	8
Dynamic Cf/(N+I) for DAQ3.4	15	15	15
Antenna Gain (dBi)	0	0	0
Antenna Height Above Ground (m)	1.5	30	30
Dynamic Sensitivity (dBm)	-112	-112	-112
Link Budget	145dB	145dB	137dB

Note: the base station Transmitter ERP is assumed to be limited to 25W (+44dBm) by regulation.

TETRA

TETRA Link Budgets for Urban Terrain - Parameters	Downlink	Uplink Mobile	Uplink Portable
Transmitter:			
Output Power (dBm)	See Note 1	40	31.8
Transmitter to Antenna Losses (dB)	See Note 1	0	0
Antenna Gain (dBi)	See Note 1	0	0
Effective Radiated Power, ERP (dBm)	44	40	31.8
Antenna Height Above Ground (m)	50	1.5	1.5
Channel Margins:			
Large Scale Fading (Shadowing) for 95% reliability	8	8	8
Other Losses (Foliage, Building Penetration, Clutter)	10	10	10
Receiver:			
Bandwidth (kHz)	18	18	18
Noise Figure (dB)	8	8	8
Dynamic Cf/(N+I) for DAQ3.4	16	16	16
Antenna Gain (dBi)	0	0	0
Antenna Height Above Ground (m)	1.5	50	50
Dynamic Sensitivity (dBm)	-107.4	-109.4	-109.4
Link Budget	133.4dB	131.4dB	123.2dB

TETRA Link Budgets for Rural Terrain - Parameters	Downlink	Uplink Mobile	Uplink Portable
Transmitter:			
Output Power (dBm)	See Note 1	40	31.8
Transmitter to Antenna Losses (dB)	See Note 1	0	0
Antenna Gain (dBi)	See Note 1	0	0
Effective Radiated Power, ERP (dBm)	44	44	31.8
Antenna Height Above Ground (m)	50	1.5	1.5
Channel Margins:			
Large Scale Fading (Shadowing) for 95% reliability	6	6	6
Other Losses (Foliage, Building Penetration, Clutter)	5	5	5
Receiver:			
Bandwidth (kHz)	18	8	8
Noise Figure (dB)	8	7	7
Dynamic SINR (C/(N+I)) for DAQ3.4	16	16	16
Antenna Gain (dBi)	0	0	0
Antenna Height Above Ground (m)	1.5	30	30
Dynamic Sensitivity (dBm)	-107.4	-109.4	-109.4
Link Budget	140.4dB	138.4dB	130.2dB

Notes:

1. The base station Transmitter ERP has been assumed to be limited to 25W (+44dBm) by regulations.

Comparing the Urban and Rural Link Budgets for DMR and TETRA, we find:

| Path | Terrain | Link Budgets | | Difference | Difference in favour of |
		DMR	TETRA		
Downlink	Urban	138dB	133.4dB	4.6dB	DMR
	Rural	145dB	140.4dB	4.6dB	DMR
Uplink Mobile	Urban	138dB	131.4dB	6.6dB	DMR
	Rural	145dB	138.4dB	6.6dB	DMR
Uplink Portable	Urban	130dB	123.2dB	6.8dB	DMR
	Rural	137dB	130.2dB	6.8dB	DMR

The table above is for TETRA base stations with diversity. However not all TETRA base station receivers have diversity, so when we take that out of the picture, we get the following:

| Path | Terrain | Link Budgets | | Difference | Difference in favour of |
		DMR	TETRA		
Downlink	Urban	138dB	133.4dB	4.6dB	DMR
	Rural	145dB	140.4dB	4.6dB	DMR
Uplink Mobile	Urban	138dB	129.4dB	8.6dB	DMR
	Rural	145dB	136.4dB	8.6dB	DMR
Uplink Portable	Urban	130dB	121.2dB	8.8dB	DMR
	Rural	137dB	128.2dB	8.8dB	DMR

WHAT LIMITS THE COVERAGE OF A PRACTICAL SYSTEM?

Link Budget

Here is the DMR and TETRA coverage in terms of both radius and area. (The Okumura-Hata coverage model for urban and rural terrains was used.)

The table below gives DMR and TETRA coverage for the Downlink.

Downlink Parameter	Urban Terrain		Rural Terrain	
	DMR	TETRA	DMR	TETRA
Link Budget	138dB	133.4dB	145dB	140.4dB
Coverage Radius	8.52km	6.3km	32km	24km
Coverage Area	228sqkm	123sqkm	3186sqkm	1764km

The table below gives DMR and TETRA mobile and portable coverage for the Uplink. (TETRA base station receive diversity is taken into account.

Uplink Parameter With Receive diversity)	Urban Terrain				Rural Terrain			
	Mobile		Portable		Mobile		Portable	
	DMR	TETRA	DMR	TETRA	DMR	TETRA	DMR	TETRA
Link Budget	138dB	131.4dB	130dB	123.2dB	145dB	138.4dB	137dB	130.2dB
Coverage Radius	8.52km	5.5km	4.9km	3.1km	32km	21km	19km	12.2km
Coverage Area	228sqkm	94sqkm	77sqkm	31sqkm	3186sqkm	1358sqkm	1119sqkm	464sqkm

Not all TETRA bases stations have receive diversity. If we take this out of the equation, we get the following:

Uplink Parameter (No Receive diversity)	Urban Terrain				Rural Terrain			
	Mobile		Portable		Mobile		Portable	
	DMR	TETRA	DMR	TETRA	DMR	TETRA	DMR	TETRA
Link Budget	138dB	129.4dB	130dB	121.2dB	145dB	136.4dB	137dB	128.2dB
Coverage Radius	8.52km	4.8km	4.9km	2.7km	32km	18km	19km	11km
Coverage Area	228sqkm	71sqkm	77sqkm	23sqkm	3186sqkm	1045sqkm	1119sqkm	358sqkm

So, link budget is the key difference when comparing DMR and TETRA coverage.

Delay Spread

In an urban coverage area, Delay Spread will not generally get much above 5us. In suburban or rural terrains it will be even less. So despite the fact that DMR has a delay spread tolerance of 28us, (compared to 15us for TETRA) this is unlikely to be a determining factor in the relative coverage between the two systems. (An exception may be at the edge of coverage in very rugged, mountainous terrain.)

TETRA π/4DQPSK modulation is more resilient to delay spread than DMR 4FSK modulation, because delay spread tolerance is a function of symbol rate, and TETRA modulation is faster (18000 symbols per second) than DMR (4800 symbols per second).

TDMA Guard Time

DMR TDMA Guard time (1ms) gives a theoretical coverage boundary of 131.25km if the terminals have 0.5ppm clock accuracy. TETRA TDMA Guard time (0.4ms) gives a theoretical coverage boundary of 41.25km if the terminals have 0.5ppm clock accuracy. Over urban terrain, this is rarely a determining factor as it is unlikely either DMR or TETRA coverage would exceed 41.25km. However, over rural terrain, where the coverage radius will likely exceed 41.25km, this is a limiting factor for TETRA

Note that the difference in coverage due to TDMA guard time is only observed when operating a number of terminals at different distances from the base station. A typical coverage drive test uses only one terminal being driven away from the base station, so the near/far problem will not be seen, giving a false picture of how the system will perform in reality.

DMR VS TETRA COMPARATIVE CELL RADIUS AND COVERAGE AREA

The link budget differences for DAQ3.4 are the major factor for comparing the relative coverage of DMR and TETRA, because they are hard and fast numbers. This section shows how many TETRA base stations are needed to cover the same area as two combined DMR base stations (to provide the equivalent four talk paths of TETRA).

Downlink

In urban terrain, two combined DMR base stations have 8.52/6.3 = 1.35 times the coverage radius of one TETRA base station.

- If the coverage area is circular, two combined DMR base stations cover 228/123 = 1.85 x the area of one TETRA base station.
- If the network was planned on urban downlink coverage, it would need 1.85 TETRA sites for *each* DMR site.

In rural terrain, two combined DMR base stations have 32/24 = 1.33 times the coverage radius of one TETRA base station.

- If the coverage area is circular, two combined DMR base stations cover 228/123 = 1.81 x the area of one TETRA base station.
- If the network was planned on rural downlink coverage, it would need 1.81 TETRA sites for each DMR site.

Uplink (DMR vs TETRA base station with Receive Diversity) - mobile terminal

In urban terrain, a DMR mobile can reach the base station from 8.52/5.5 = 1.55 x the radius a TETRA mobile can.

- If the coverage area is circular, a DMR mobile can reach the base station from 228/94 = 2.43 x the area a TETRA mobile can.
- If the network was planned on urban uplink mobile coverage, there would need to be 2.43 TETRA sites for each DMR site.

In rural terrain, a DMR mobile can reach the base station from 32/21 = 1.52 x the radius a TETRA mobile can.

- If the area is circular, a DMR mobile can reach the base station from 3186/1358 = 2.35 x the area a TETRA mobile can.
- If the network was planned on rural uplink mobile coverage, it would need 2.35 TETRA sites for each DMR site.

Uplink (DMR vs TETRA base station with Receive Diversity) - portable terminal

In urban terrain, a DMR portable can reach the base station from 4.9/3.1 = 1.58 x the radius a TETRA portable can.

- If the area is circular, a DMR portable can reach the base station from 77/31 = 2.48 x the area a TETRA portable can.
- If the network was planned on urban uplink portable coverage, it would need 2.48 TETRA sites for each DMR site.

In rural terrain, a DMR portable can reach the base station from 19/12.2 = 1.56 x the radius a TETRA portable can.

- If the area is circular, a DMR portable can reach the base station from 1119/464 = 2.41 x the area a TETRA portable can.
- If the network was planned on rural uplink portable coverage, it would need 2.41 TETRA sites for *each* DMR site.

Uplink (DMR vs TETRA base station without Receive Diversity) - mobile terminal

In urban terrain, a DMR mobile can reach the base station from 8.52/4.8 = 1.78 x the radius a TETRA mobile can.

- If the area is circular, a DMR mobile can reach the base station from 228/123 = 3.21 x the area a TETRA mobile can.
- If the network was planned on urban uplink mobile coverage, it would need 3.21 TETRA sites for each DMR site.

In rural terrain, a DMR mobile can reach the base station from 32/18 = 1.78 x the radius a TETRA mobile can.

- If the area is circular, a DMR mobile can reach the base station from 3186/1045 = 3.05 x the area a TETRA mobile can.
- If the network was planned on rural uplink mobile coverage, there would need to be 3.05 TETRA sites for *each* DMR site.

Uplink (DMR vs TETRA base station without Receive Diversity) - portable

In urban terrain, a DMR portable can reach the base station from 4.9/2.7 = 1.81 x the radius a TETRA portable can.

- If the area is circular, a DMR Portable can reach the base station from 228/71 = 3.35 x the area a TETRA portable can.
- If the network was planned on urban uplink portable coverage, there would need to be 3.35 TETRA sites for *each* DMR site.

In rural terrain, a DMR portable can reach the base station from 19/11 = 1.73 x the radius a TETRA portable can.

- If the area is circular, a DMR Portable can reach the base station from 1119/358 = 3.12 x the area a TETRA portable can.
- If the network was planned on rural uplink portable coverage, there would need to be 3.12 TETRA sites for each DMR site.
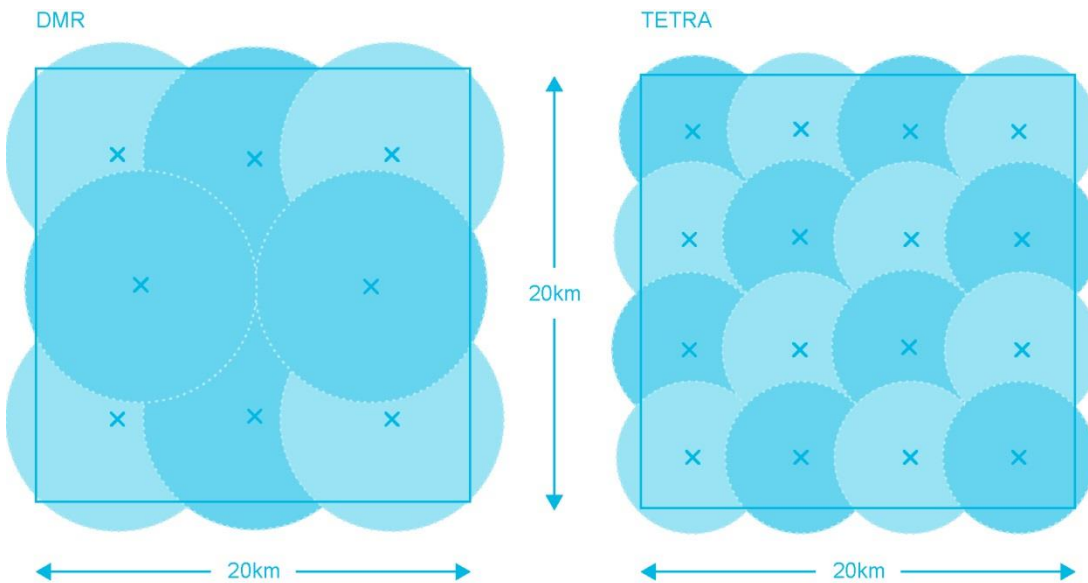
BRINGING THE NUMBERS TO LIFE

These comparisons assume operation at same the frequency. In Europe, TETRA is only licenced at UHF from 380-430MHz. DMR can be used at VHF, UHF and 800MHz, so the best choice can be made for the terrain, further increasing DMR's advantage.
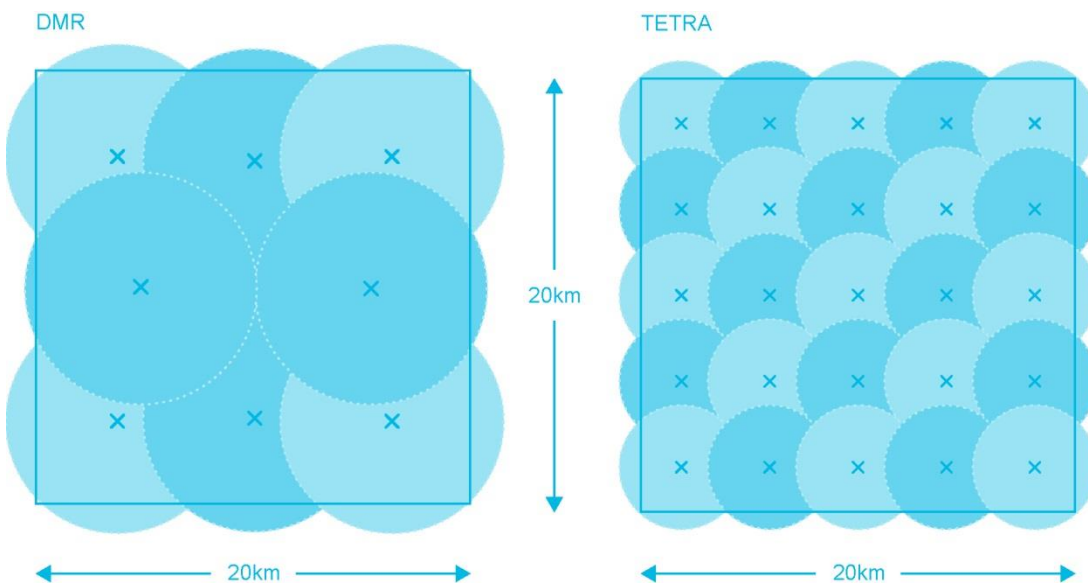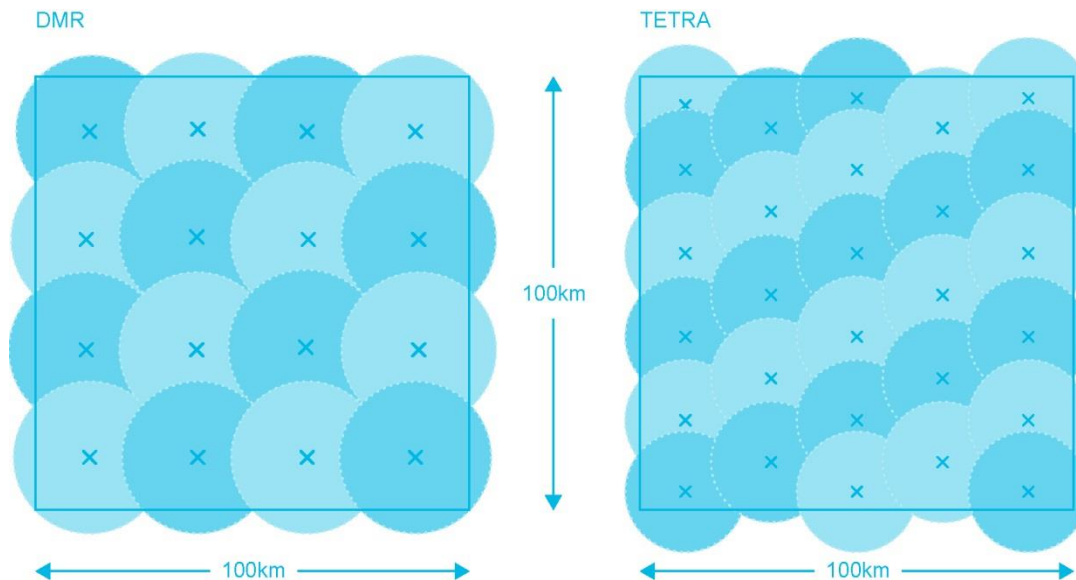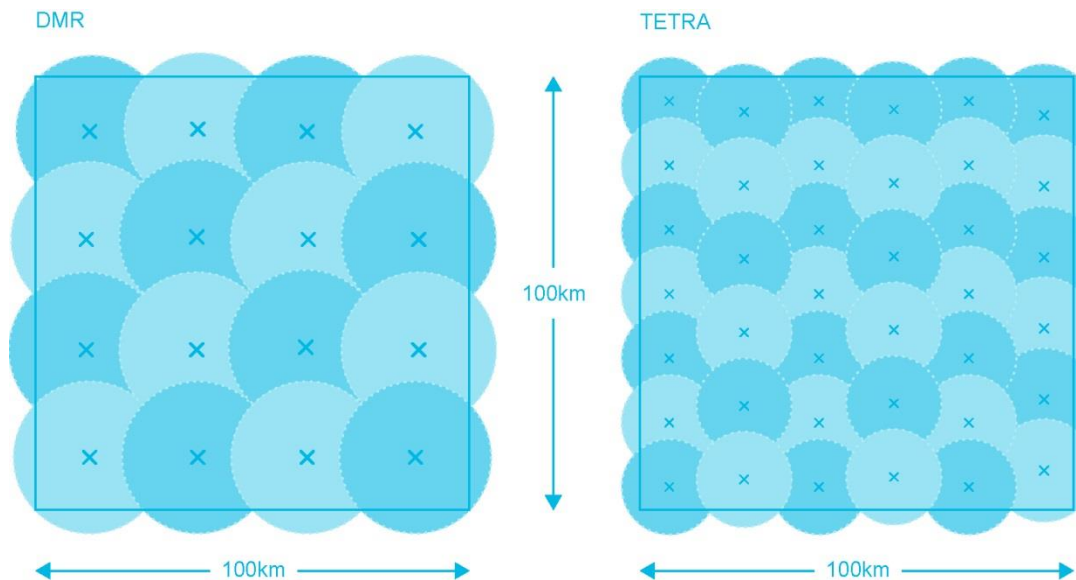
URBAN

DMR vs TETRA with base station Receive Diversity

If a network has Portable Uplink coverage and the TETRA base stations have receive diversity, this diagram compares how many DMR and TETRA sites we need to cover a town of 400sqkm. Eight DMR sites comfortably cover the town, whereas 16 TETRA sites (with base station Rx Diversity) are needed.

DMR vs TETRA without base station Receive Diversity

If a network has Portable Uplink coverage and the TETRA base stations did not have receive diversity, this diagram shows how many DMR and TETRA sites we need to cover a town of 400sqkm. Eight DMR sites comfortably cover the town, whereas 25 TETRA sites (without base station Rx Diversity) are needed.

RURAL

DMR vs TETRA with base station Receive Diversity

If we were planning a network with Portable Uplink coverage and the TETRA base stations had receive diversity, this diagram shows how many DMR and TETRA sites we need to cover a rural area of 10000sqkm: 16 DMR sites comfortably cover the area, whereas 28 TETRA sites with base station Rx Diversity are needed.

DMR vs TETRA without base station Receive Diversity

If we were planning a network with Portable Uplink coverage and the TETRA base stations did not have receive diversity, this diagram shows how many DMR and TETRA sites we need to cover a rural area of 10000sqkm: Sixteen DMR sites comfortably cover the area, whereas 39 TETRA sites without base station Rx Diversity are needed.

REAL LIFE EXAMPLES

As stated in the introduction, the comparisons in this paper are based on measurable factors affecting coverage from a theoretical point of view. The examples below are of existing European TETRA systems, all of which indicate substantially poorer coverage than the theoretical analysis predicted in this paper

UK

A UK-wide TETRA system has 3465 sites. Using the county of Cambridgeshire as an example, 330 sites cover 3300km^2 - an average of 100km^2, or 5.6km coverage radius per site.

The predictions for portable uplink coverage radius in this paper for TETRA with base station receive diversity are 3.1km for urban terrain and 12.2km for rural terrain, so the actual coverage radius is heavily weighted towards the urban model.

Cambridgeshire has several small cities (eg: Peterborough, Cambridge and Ely), but is mostly flat rural terrain, so the predictions would have led us to expect better coverage than has been achieved by this system.

AUSTRIA

This TETRA network has 650 sites. The area is 83,858km^2, which gives an average coverage area of 118km^2 per site or 6.1km coverage radius.

NETHERLANDS

This TETRA network in the Netherlands has 550 sites. The area is 41,526km^2, much of which is flat. This gives an average coverage area of 75km^2 or 4.9km coverage radius per site.

GERMANY

The Federal Republic of Germany covers 357,000km^2, approximately 54% agricultural land, 29% forest and 12% built up areas.

A TETRA network with 3118 sites covers 80% of the area of the country (286,000km$^{2)}$). This gives an average coverage area of 92km^2 or 5.4km coverage radius per site.

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