

White paper

# Comparative assessment of TETRA versus LTE-based PPDR networks

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# 1 Executive summary

## 1.1 Introduction

Voice remains the foundation of public protection and disaster relief (PPDR) communications. For frontline responders, reliable mission-critical voice enables situational awareness, co-ordination and safety, especially in unpredictable or high-stress environments. This paper compares the performance of the UK's **Airwave** (TETRA) network and the **Emergency Services Network** (ESN, LTE-based) across coverage, resilience, special features and future-readiness, drawing on technical evidence, international examples and operational considerations.

## 1.2 Coverage

TETRA continues to provide more consistent and predictable mission-critical coverage than LTE-based PPDR networks:

- **Superior coverage physics:** TETRA's ~400MHz frequency offers better propagation, ~5–6dB lower path loss and more reliable wide-area coverage than ~800MHz LTE.
- **Building penetration and diffraction:** TETRA signals diffract more effectively and suffer lower building-entry loss, whereas higher-frequency LTE signals drop off more abruptly behind obstacles and underperform indoors.
- **Operational predictability:** TETRA networks have known black spots (localised areas where signal is very weak even though service is available in the broader area) which responders can anticipate due to 20 years of service experience; ESN's practical coverage has not yet been tested and still depends on significant in-building upgrades and expansion.
- **Programme timelines and costs:** ESN readiness depends on 1–2-year test cycles; the 2029 timeline is uncertain and programme costs are now materially higher than originally expected and above the cost of operating the Airwave network.

## 1.3 Resilience

TETRA offers higher and more predictable resilience due to its purpose-built design:

- **Purpose-built resilience:** TETRA uses dedicated spectrum, hardened sites (typically improved power resilience) and dual transmission paths to avoid single points of failure.
  - Due to ESN's weaker coverage and wave propagation, the network requires a higher number of sites to cover the same area, which in turn increases the total cost of hardening the network.
- **Shared-network dependencies in LTE:** ESN relies on a commercial LTE radio network, backhaul and power, creating multiple interdependencies and single-exchange vulnerabilities.

- **Performance during incidents:** during power outages or major events, TETRA maintains service, while LTE performance depends on commercial layers that are harder to assure for PPDR.
- **Network congestion:** public LTE-based PPDR networks are exposed to public-driven congestion, which can reduce available capacity and, in severe cases, prevent devices from attaching to the network before priority rules take effect. Addressing this structurally would require dedicated spectrum for ESN's mission-critical services, whereas TETRA is insulated from public traffic entirely through its dedicated PPDR-only spectrum.
- **Layered architecture:** TETRA + LTE/Wi-Fi (for example, Dimetra Connect) offers multi-bearer redundancy, while mobile-only fallback provides limited resilience benefit (for example, different public LTE networks can have the same single points of failure).

## 1.4 Special features

Key TETRA capabilities remain unmatched by operational LTE/ESN solutions:

- **Direct Mode Operation (DMO):** TETRA's mature, off-network safety capability is well understood and used. LTE has no operational equivalent, and the proposed capability ProSe (sidelink) remains developmental.
- **Ground-to-air:** TETRA provides a certified, proven aviation solution, whereas LTE lacks a mission-critical airborne capability and faces regulatory and technical barriers.
- **Predictable group behaviour:** fast group call set-up, deterministic priority and congestion resilience remain native TETRA strengths not yet replicated in LTE-based PPDR deployments.

## 1.5 Future of PPDR

PPDR communications are likely to shift towards hybrid models where modernised TETRA networks remain central for mission-critical voice, and LTE/5G provides broadband data and supplementary resilience:

- **Modernised TETRA platform:** Airwave has been significantly upgraded with IP-based backhaul/core, modern monitoring and security, ensuring long-term viability.
- **Continued investment:** TETRA networks worldwide continue to implement hardware and software refresh cycles, strengthened encryption, enhanced coverage and broadband integration.
- **International hybrid strategy:** countries including Germany, France, Finland, Norway, Denmark and the USA are retaining TETRA and land mobile radio (LMR) well into the 2030s, while deploying LTE/5G in parallel for broadband services.
- **Staged convergence, not replacement:** a single network will likely never provide the complete answer, making hybrid working and convergence the long-term global norm.
- **Satellite as a complementary bearer:** low Earth orbit (LEO) satellite links may offer useful backhaul or contingency connectivity in remote or degraded environments, but they cannot address core PPDR coverage needs, lack proven mission-critical resilience, and should be viewed only as a supplementary capability within a wider multi-bearer model.

## 1.6 Conclusion

The evidence highlights that **TETRA remains the benchmark for mission-critical voice** in PPDR operations. Its **superior coverage physics, purpose-built resilience** and **operationally proven feature set** – including capabilities not yet available in LTE-based PPDR solutions – provide responders with a level of **predictability** and **assurance** that broadband networks cannot currently match. In contrast, the UK's ESN's mission-critical voice capabilities, coverage enhancements and operational readiness remain subject to ongoing development, testing, and programme and cost uncertainties. As a result, the most robust strategy for the UK is to **retain TETRA as the primary platform for mission-critical voice**, while **progressively integrating LTE** in a hybrid approach to deliver broadband data, enhanced situational awareness and additional resilience as those capabilities mature.

## 2 Introduction

Voice communication is the lifeline of public protection and disaster relief (PPDR) operations. For police, fire, ambulance and other emergency responders, the ability to communicate instantly, reliably and predictably in the most challenging environments is fundamental to effective incident response and public safety. While data and broadband applications are growing in importance, it is voice that underpins situational awareness, command and the rapid co-ordination of resources in the field.

For over two decades, the UK's Airwave network, built on TETRA technology, has provided dedicated, resilient and highly predictable voice services for emergency services nationwide. This purpose-built system has enabled responders to operate 'heads up' in the field (i.e. without the need to spend time watching screens), secure in the knowledge that a single voice call can summon support, information or co-ordinate a new response, even under adverse conditions.

The UK Home Office's Emergency Services Network (ESN) programme aims to transition PPDR communications to a public LTE-based network, promising enhanced data and multimedia capabilities. However, the timeline for this transition has shifted repeatedly, with Airwave now expected to remain in service at least into the late 2020s, reflecting the continued need to maintain assured mission-critical voice at least during the period while ESN's delivery progresses.

In this context, the central challenge is not simply *when* to migrate to a new technology, but *how* to ensure that the core requirement for robust, mission-critical voice is maintained throughout the transition and afterward. While data-enabled capabilities are an essential part of the long-term vision for PPDR communications, the risks associated with the transition – including coverage variability, resilience dependencies and the maturity of certain LTE-based features – make it critical to understand how current and future platforms compare in practice.

This paper provides an evidence-based comparison of the UK's two principal PPDR communication platforms, namely Airwave (TETRA) and ESN (LTE-based). It examines their respective strengths and limitations across coverage, resilience, special features and futureproofing, drawing on technical analysis, international experience and operational realities. The aim is to inform policy and procurement decisions by clarifying the technical and operational implications of each approach, and by highlighting the factors that will determine the success of any future migration or hybrid model.

In doing so, this paper recognises the likelihood and benefit of broadband-enabled PPDR communications in the long term, while clearly underscoring the importance of maintaining proven, trusted mission-critical voice capabilities that frontline responders rely upon today.

## 3 Network coverage

### 3.1 Coverage comparison of TETRA versus LTE-based solutions for PPDR

From a user-experience perspective, TETRA currently provides more consistent and predictable network coverage for PPDR mission-critical voice communications than LTE-based solutions.

This advantage is driven by a combination of lower-frequency operation, which supports more favourable signal propagation (how radio signals travel through the environment), and years of proven real-world performance that give users confidence in how the network behaves and where any coverage black spots (localised areas where signal is very weak even though service is available in the broader area) are located.

The sections that follow set out the technical and operational evidence underpinning these statements and explain how they translate into differences in user experience.

### 3.2 Propagation physics and delivery readiness for PPDR coverage

Signals operating at lower frequencies experience significantly less path loss than higher-frequency signals, and they also propagate more effectively around physical obstacles due to stronger diffraction (the bending of radio waves around obstacles – see Section 3.2.2). This translates directly into larger achievable cell radii (the maximum distance from a base station over which reliable service can be provided), improved indoor reach and higher link margins (the difference between the received signal strength and the minimum level required for reliable communication) at the edge of coverage, all of which are critical for PPDR voice communications.

#### 3.2.1 Path loss

Path loss describes the reduction in radio signal power as it propagates from a transmitting antenna to a receiving antenna through space and the surrounding environment. It represents the cumulative attenuation (loss of signal strength) caused by distance, frequency, terrain, clutter and atmospheric effects, and is typically expressed in decibels (dB). Path loss is a fundamental parameter in radio-link budget calculations, determining whether the received signal remains above the minimum level required for reliable communication.

Higher path loss reduces coverage range, degrades signal quality at the cell edge (the outer boundary of a cell where coverage is weakest and most vulnerable to disruption) and increases the likelihood of call failures. As defined by the International Telecommunication Union Radiocommunication Sector (ITU-R) in its *Calculation of free-space attenuation* paper,<sup>1</sup> path loss can be expressed as:

$$L_{bf} = 32.4 + 20 \log f + 20 \log d$$

<sup>1</sup> [ITU-R \(2016\), \*Calculation of free-space attenuation\*.](#)

Where:

- $L_{bf}$ : free space basic transmission loss (dB)
- $f$ : frequency (MHz)
- $d$ : distance (km).

Given the relationship between frequency and path loss, for a fixed distance, an LTE system operating at approximately 800MHz experiences an additional 5–6dB of path loss compared with a TETRA system operating at around 400MHz. In decibel terms, every 3dB of additional loss corresponds to roughly a halving of received power, so an extra 5–6dB means the received signal at 800MHz is only around one-quarter as strong as at 400MHz.

In practical terms, this difference must be offset either by substantially increased transmit power or by a reduction in achievable cell radius. For PPDR networks, which must provide reliable coverage over wide geographical areas and at the edge of the network, this additional loss represents a material disadvantage.

### 3.2.2 Building entry loss (via signal diffraction and penetration)

As discussed in the preceding section, lower-frequency radio signals exhibit stronger diffraction, allowing them to propagate more effectively around obstacles and beyond direct line-of-sight. For indoor and near-building scenarios, this behaviour becomes particularly important. Diffraction enables signal energy to bend around building edges, corners and openings, allowing it to reach indoor environments even where direct penetration through external walls is limited, thereby reducing the severity of building entry loss experienced by users.

In addition to free-space path loss, PPDR users frequently operate inside buildings, underground structures and enclosed environments, where additional attenuation arises not only from signal penetration through materials, but also from how effectively radio signals diffract around building edges and into indoor spaces. These effects are collectively referred to as building entry loss and, in many PPDR scenarios, can exceed the impact of distance-related losses. Lower-frequency signals, such as those used by TETRA, diffract more effectively around obstacles, corners and gaps, allowing the signal to ‘bend’ into black spots, where higher-frequency LTE signals weaken more abruptly (see Figure 3.1 and Figure 3.2). This improved diffraction behaviour is a key contributor to lower building entry loss (stronger in-building coverage) for TETRA because more signal energy reaches the indoor environment, even before penetrating the outer structure. As a result, lower-frequency systems maintain more reliable indoor and behind-building coverage before any dedicated in-building solutions are deployed.

Internationally recognised propagation models defined by the ITU-R<sup>2</sup> show that building entry loss increases with operating frequency and varies significantly by building type. In addition, Ofcom, in its *Building Materials and Propagation* report,<sup>3</sup> concluded that higher-frequency signals experience greater attenuation through common building materials than lower-frequency signals (see Figure 3.3).

<sup>2</sup> [ITU-R \(2023\), \*Prediction of building entry loss\*.](#)

<sup>3</sup> [Ofcom \(2014\), \*Building Materials and Propagation\*.](#)

As a result, higher-frequency networks experience greater indoor attenuation and less predictable indoor performance than lower-frequency systems. In the UK context, TETRA systems therefore experience materially lower building entry loss (stronger in-building coverage) than LTE-based networks. When combined with the higher path loss at 800MHz, this leads to reduced indoor link margins and an increased likelihood of coverage gaps inside buildings.

While LTE networks can, in principle, mitigate these physical disadvantages through network densification, in-building enhancements and advanced features, their effectiveness for PPDR communications depends on timely delivery at significant scale. In the UK, the ESN programme includes enhancement of a defined set of critical indoor locations, approximately 1500 commercial and public-sector buildings. However, the total number of sites requiring enhancement remains uncertain due to evolving coverage assumptions, building usage patterns and operational requirements. Any increase in scope would directly affect programme scale, cost and delivery timelines. These activities also coincide with heightened investment demands across the wider mobile sector, including major network modernisation and integration programmes, increasing the risk of supply-chain, resource and scheduling constraints.

PPDR operations are not confined to this defined building set under the ESN programme. Emergency responders may be required to operate in any environment, including residential properties, which represent a significant proportion of real-world incidents and are outside the current enhancement scope. As a result, additional indoor coverage gaps (i.e. on top of the already identified 1500 sites) may only become apparent during live operations and transition-phase trials. At present, it is not clear how responsibility for funding, delivering or maintaining any further in-building enhancements beyond the defined building set would be allocated, including who would bear the cost of addressing newly identified black-spots.

By contrast, TETRA's coverage advantages are not only rooted in favourable propagation physics, but are already realised through a mature, operationally proven PPDR network with well-understood coverage limitations and established mitigations, rather than being dependent on the future delivery of large-scale enhancement programmes.

### 3.3 What coverage differences mean for PPDR users

For PPDR users, communication performance is judged primarily by reliability, predictability and confidence that voice communications will function in operationally critical environments. The coverage characteristics discussed earlier translate directly into day-to-day user experience.

#### 3.3.1 Localised black spots

Emergency services also frequently operate in rural and remote areas, often close to the edge of network coverage. In these situations, reductions in link margin are experienced directly by users as audio clipping, delayed call set-up or intermittent connectivity.

Lower-frequency systems have larger cell footprints and lower path loss and, therefore, tend to exhibit more gradual and predictable degradation as users move away from the serving site. By contrast, LTE-based coverage can degrade more abruptly at the cell edge, meaning that when a black spot is encountered, users may experience a sudden loss of connectivity rather than a gradual decline in service.

Figure 3.1: Wave diffraction over buildings for TETRA versus LTE

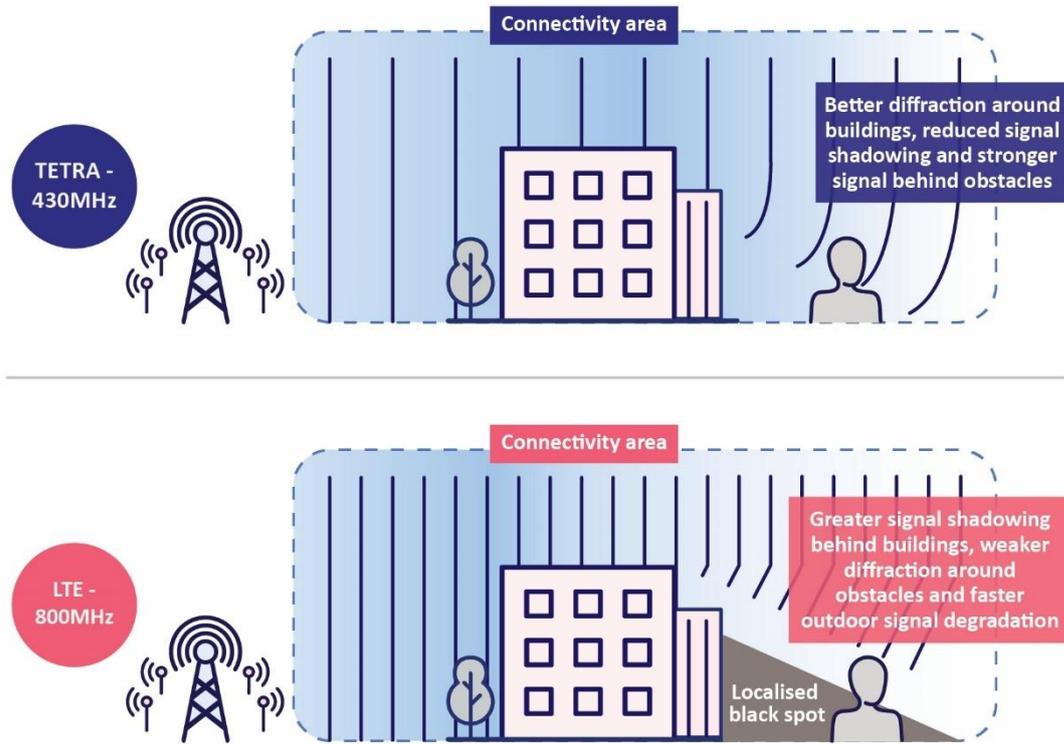
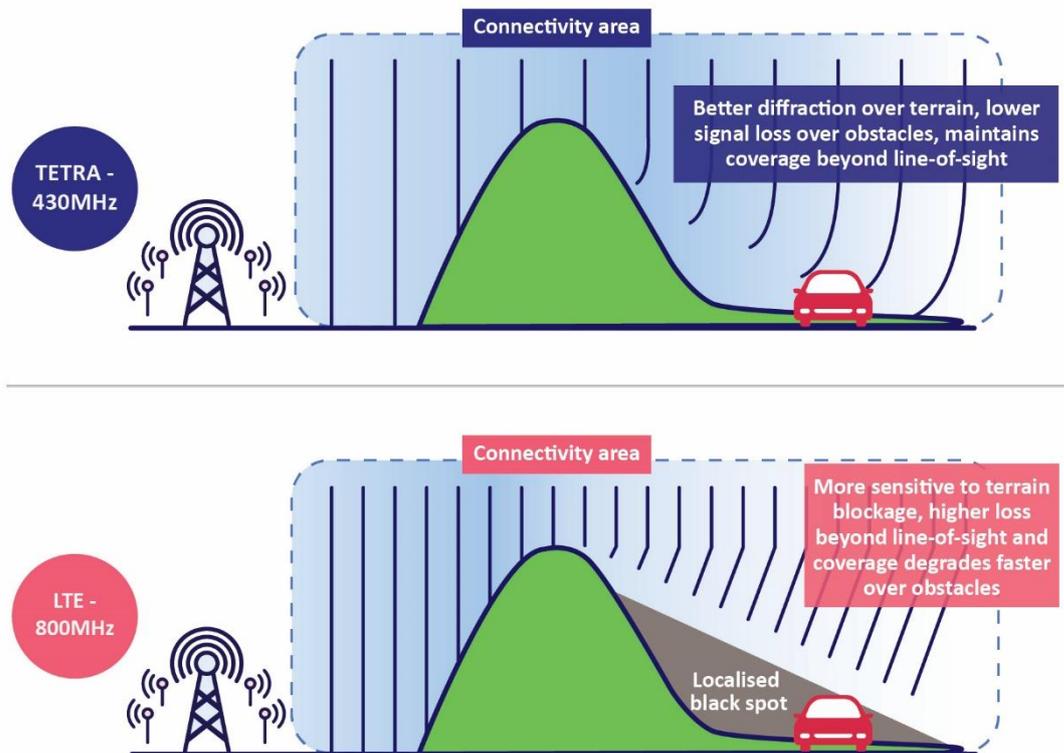


Figure 3.2: Wave diffraction over hills for TETRA versus LTE



### 3.3.2 Indoor coverage

Indoor environments account for a large proportion of PPDR operations. Due to lower building entry loss, waves are able to diffract and penetrate building walls better. As such, TETRA users typically experience more consistent voice performance indoors, resulting in fewer black spots, fewer repeated call attempts and more reliable call set-up in challenging environments such as basements and reinforced concrete structures. In addition, given the long history of PPDR services being hosted on TETRA networks, indoor black spots are generally known and established operational workarounds exist. For example, users may already know that coverage is limited in specific basement levels of older hospitals, underground car parks or reinforced stairwells in high-rise buildings, and plan their communications accordingly. In these situations, teams may pause to relay information before entering known black spots, use alternative positioning, or rely on established procedures to maintain situational awareness. By contrast, LTE indoor performance is more variable and depends heavily on macro network density and the availability of dedicated in-building solutions.

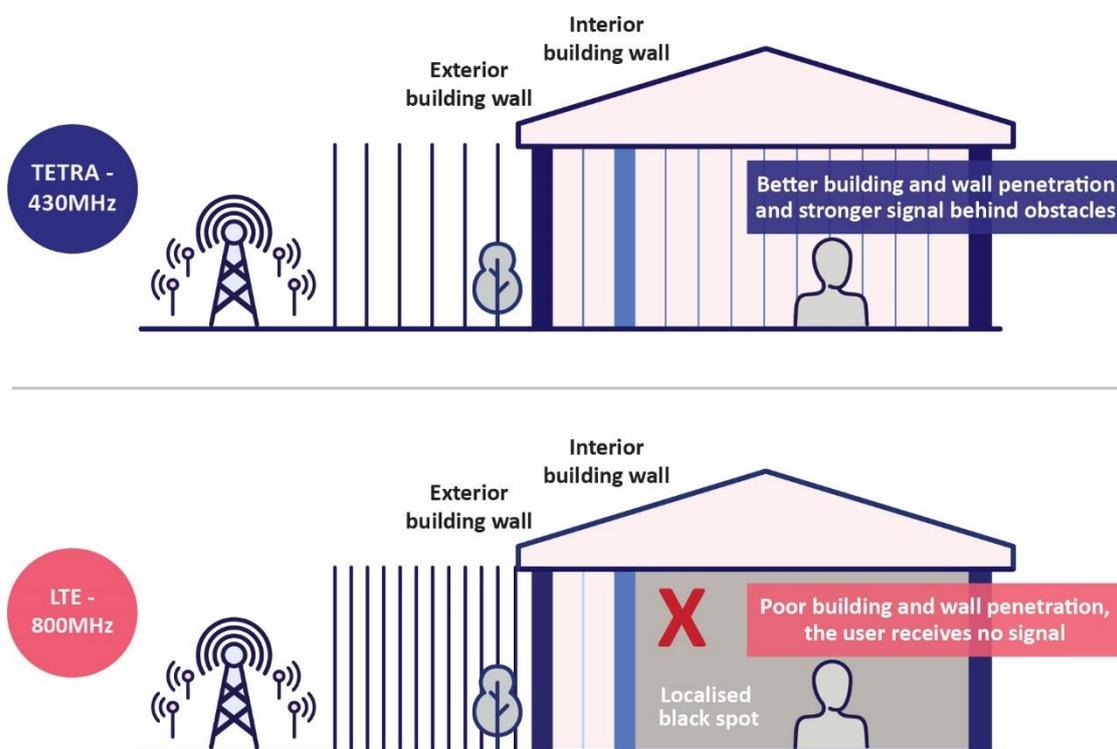
The general public, who use the same network as ESN users, already experience this in-building problem when trying to use their mobile phone indoors, and Wi-Fi is often necessary when seeking to maintain connectivity throughout the home.<sup>4</sup> For example, going to a friend's house may result in having to get the friend's Wi-Fi password to make up for poor indoor coverage in that house. It would be unreasonable – and a security concern for businesses and individuals – to expect PPDR users to have to ask for the Wi-Fi password in every potential location to get coverage, given that they are using exactly the same network as normal users do and thus will be experiencing the same indoor coverage not-(black)spots as the general public do.

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<sup>4</sup>

[Analysys Mason \(2025\), \*Wireless network data traffic: worldwide trends and forecasts 2024–2030\*.](#)

Figure 3.3: Wave propagation through building walls for TETRA versus LTE-based networks



### 3.3.3 User confidence and operational familiarity

Beyond technical performance, user experience is strongly influenced by familiarity and trust. TETRA has been used operationally in the UK for many years, supported by a network specifically engineered for mission-critical communications. This purpose-built design, combined with extensive real-world use, has created a shared understanding among users of where coverage works well, where it does not, and how the system behaves under stress. Together, these factors underpin a high level of operational confidence. Any transition to a new communications platform is therefore likely to face resistance unless the benefits are clear, tangible and consistently experienced by users.

### 3.3.4 Programme delivery uncertainty

Although LTE-based solutions can, in principle, overcome many of the propagation disadvantages described above, their effectiveness depends on timely and large-scale programme delivery.

The ESN programme has experienced several significant delays in the past, and the 2029 target for service transition remains uncertain given the scale of remaining work. This work includes the deployment of approximately 1500 additional sites (this figure is uncertain given evolving coverage assumptions, building usage patterns and operational requirements, and only refers to commercial and public-sector buildings), in-building solutions, and the development and testing of mission-critical service functions. Importantly, full operational validation for PPDR typically requires 12–24

months of integrated field testing and user acceptance, meaning that any slippage in deployment milestones directly pushes back the earliest feasible transition date.

These uncertainties add further risk to near-term LTE-based coverage readiness compared with the already-operational and predictable TETRA network. As a result, while responsibility for the design and delivery of PPDR communications infrastructure sits at national level, Police and Crime Commissioners must manage the operational consequences of any coverage gaps, despite having limited control over the underlying network.

### 3.3.5 Cost and service considerations

Cost and service considerations also play an important role in operational decision-making. Taken together, the available figures indicate that, on an annualised basis, overall ESN-related expenditure has already increased relative to the cost of the TETRA network and remains subject to further upward pressure as the programme continues to mature.

Prior to ESN, official estimates indicate that combined Airwave and legacy system costs were approximately GBP450 million per annum.<sup>5</sup> However, in 2025, the Competition and Markets Authority (CMA) introduced a price cap that reduced Airwave charges by almost GBP200 million per annum,<sup>6</sup> aiming to ensure that emergency services pay a fairer price for the TETRA network.

The original ESN business case assumed an annual cost of around GBP250 million, representing a projected saving of roughly GBP200 million compared with the then-current Airwave arrangements.<sup>7</sup> However, published delivery contracts with EE and IBM indicate that actual ESN costs are expected to be significantly higher, with annualised expenditure estimated at around GBP370 to GBP420 million per annum<sup>8,9</sup> once the programme is fully operational.

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<sup>5</sup> [UK Parliament \(2024\), \*Airwave Service and Emergency Services Network: Expenditure\*.](#)

<sup>6</sup> [GOV.UK \(2025\), \*CMA wins appeal in emergency services case\*.](#)

<sup>7</sup> [UK Parliament \(2024\), \*Airwave Service and Emergency Services Network: Expenditure\*.](#)

<sup>8</sup> [GOV.UK \(2024\), \*ESMCP – Mobile Services Agreement for the Emergency Services Network\*.](#)

<sup>9</sup> [GOV.UK \(2025\), \*User Services for Emergency Services Network \(ESN\)\*.](#)

## 4 Network resilience

### 4.1 Network resilience comparison of TETRA versus LTE for PPDR

#### 4.1.1 Architectural resilience (TETRA versus LTE)

TETRA is purpose-built for PPDR. Its dedicated spectrum, hardened sites and dual backhaul paths (two independent routes to the core) limit the impact of individual failures. Backup power systems and controlled change processes help to ensure the network behaves predictably during outages.

LTE-based PPDR relies on commercial networks not originally designed for mission-critical continuity. To achieve a level of resilience comparable to TETRA, LTE-based networks would likely require enhanced measures such as site hardening, a dedicated mission-critical core, and the implementation of priority and pre-emption mechanisms. These protections sit on top of infrastructure shared with the public, making failure modes more complex and sometimes harder to contain.

As a result, TETRA offers more intrinsic, self-contained resilience, while LTE-based PPDR introduces a wider range of dependencies and potential points of failure.

#### 4.1.2 Redundancy and multiple bearer<sup>10</sup> considerations

TETRA includes native service-continuity mechanisms such as fallback modes, Direct Mode Operation (DMO), deterministic failover (automatic recovery behaviour) and dual power and backhaul connections. These mechanisms have been proven in real incidents.

Multi-bearer solutions like Dimetra Connect extend resilience by allowing devices to use TETRA, LTE and Wi-Fi bearers (the wireless links carrying communications), while keeping the TETRA talkgroup model (a structured group-calling approach in which users are organised into predefined operational groups, and a single transmission is instantly heard by all members of the group). This protects continuity without requiring users to change their standard operating procedures (how they interact with their radios in practice).

Full radio bearer redundancy for ESN depends on roaming, network sharing or multi-operator SIM profiles (devices connecting to more than one operator). These follow 3GPP standards (the global rules for commercial mobile networks) and depend on external agreements and commercial infrastructure, making behaviour during emergencies less predictable.

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<sup>10</sup> Also known as multiple radio access technologies (multi-RAT) in 3GPP terminology.

## 4.2 Network architectures and operational delivery of resilience

TETRA and LTE-based PPDR differ fundamentally in how they behave under stress. TETRA's architecture is dedicated to emergency services with tightly controlled dependencies. LTE-based PPDR operates on commercial mobile infrastructure, where shared equipment, fibre paths and upgrade cycles introduce broader interconnections and more varied failure modes.

The subsections below outline the specific architectural characteristics of both systems and explain how these translate into day-to-day operational resilience.

### 4.2.1 TETRA architecture

TETRA operates as a dedicated PPDR network, meaning its radio sites, spectrum, core network and service logic are reserved exclusively for emergency services. This design provides several structural advantages:

- Dual power systems (battery and generator backup) that maintain service during extended outages.
- Redundant backhaul paths (two independent connectivity routes to switching centres), reducing the risk that a single event will isolate multiple sites.
- Hardened sites (reinforced physical infrastructure), designed to remain operational during severe weather, power failures or flooding.
- Controlled change and upgrade processes (strict testing and roll-out of updates), which limit unplanned downtime.
- Native mission-critical voice features, including instant call set-up, group calls, priority and pre-emption, which continue to operate reliably even when parts of the network are degraded.

Failures are usually local and contained. When a link or exchange fails, traffic is rerouted through an alternative path, meaning users typically retain service even during partial network outages.

### 4.2.2 LTE-based PPDR architecture

LTE-based PPDR services rely on commercial mobile networks, which introduces different architectural characteristics:

- Shared radio access network (RAN) equipment (radio infrastructure used by both the public and emergency services).
- Shared power and backhaul systems, including commercial fibre networks that may serve multiple locations.
- Commercial maintenance and upgrade cycles, which can introduce changes outside PPDR control.
- Mixed physical dependencies, such as shared cabinets, masts or data centre environments.

To meet PPDR resilience requirements, commercial LTE networks must be upgraded with PPDR-specific measures, including:

- site hardening (additional physical reinforcement and improved power resilience)
- a separate mission-critical core (3GPP-defined mission-critical services (MCX) for voice, video and data over LTE/5G, including group calls, emergency alerts and priority handling)<sup>11</sup>
- assured backhaul (higher resilience standards for transport links)
- priority and pre-emption configuration (ensuring PPDR users remain ahead of public traffic).

Even with these enhancements, many commercial sites retain single points of failure (components whose failure results in site-level outage), and clusters of sites can share a single upstream routing path, meaning a single fault may affect multiple locations simultaneously.

Because LTE resilience depends on several layers (RAN, transport, core, device firmware, SIM profiles and mission-critical voice applications), the potential failure modes can be more varied and more difficult to isolate. This increases the operational burden on integration, testing and ongoing assurance.

As mentioned earlier, due to the reduced signal propagation capacity of LTE-based networks, a larger number of sites will be required to achieve the same coverage area, making site-hardening requirements more extensive and expensive.

#### 4.2.3 Multiple radio bearer redundancy (Dimetra Connect versus pure 3GPP MCX)

Modern PPDR architectures are increasingly looking to use multiple radio network bearers to improve resilience. Dimetra Connect provides a strong example of this approach:

- It gives devices access to TETRA, LTE and Wi-Fi bearers (the wireless links used to carry communications).
- Devices can move between bearers automatically while maintaining the TETRA talkgroup model (shared group-based communication).
- No changes to user workflow are required, preserving the operational simplicity that emergency services rely on.
- Coverage gaps or temporary outages in any single bearer have a reduced operational impact.

By contrast, pure 3GPP LTE redundancy depends on mechanisms such as roaming, network sharing or multi-operator SIM provisioning (devices that are able to register on more than one commercial operator). These mechanisms follow 3GPP standards (international rules governing commercial mobile networks) rather than PPDR-specific design principles. As a result, they depend on external commercial agreements and infrastructure, and may behave less predictably during emergencies.

<sup>11</sup> 3GPP MCX are defined in 3GPP [TS 22.280](#) and related standards as a suite of standardised broadband mission-critical communication services including MCPTT, MCVideo and MCDData.

## 4.3 What network resilience means for users

The practical impact of resilience is seen in how networks behave during outages, major incidents and periods of high demand. Although both TETRA and LTE-based networks perform well under normal conditions, their different architectures produce distinct behaviours under stress.

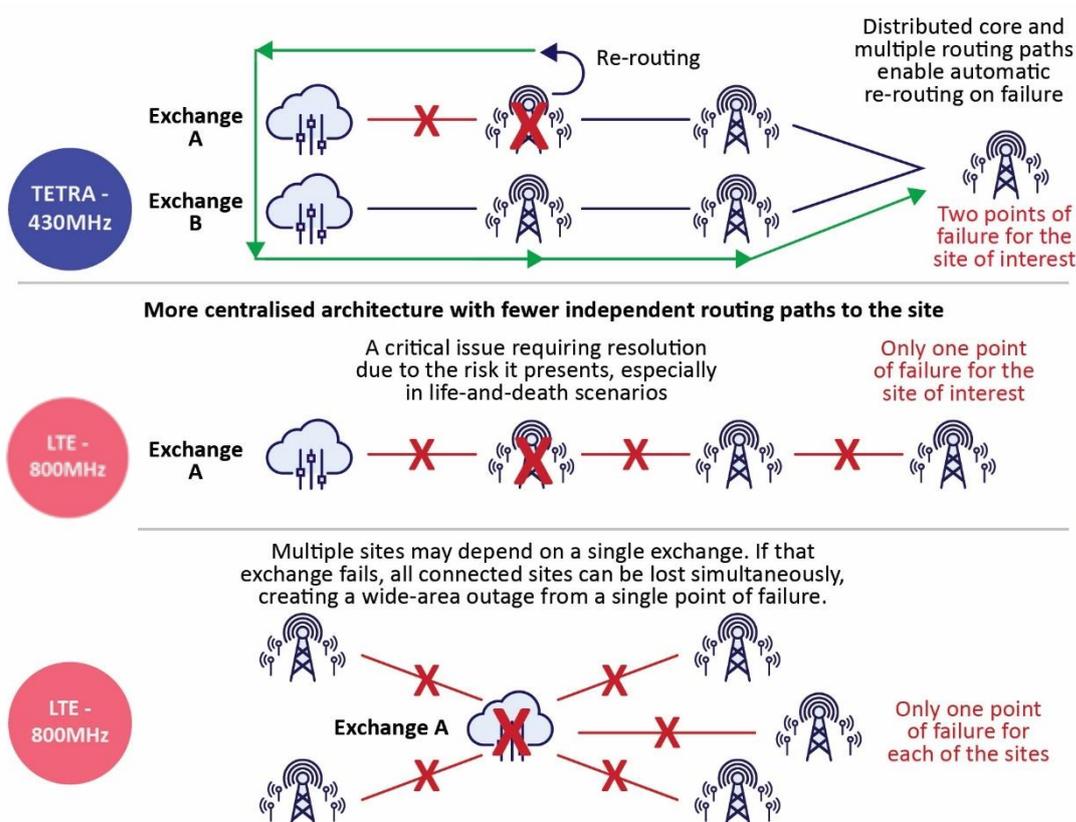
### 4.3.1 Behaviour during outages and degraded conditions

When parts of the network are impaired, for example through loss of backhaul (the link connecting a site to the core), power issues or local equipment faults, TETRA typically degrades gradually and predictably. Users often retain stable voice, consistent call set-up and reliable group communication, with any deterioration usually contained to a local area. These well-understood behaviours allow responders to adjust operations while maintaining situational awareness.

TETRA's built-in redundancy also limits the impact of more significant site or exchange-level failures. Each site usually has two independent backhaul routes and redundant switching, so a single fault is unlikely to result in loss of service. Traffic is automatically rerouted through the alternative path, allowing communications to continue, even during equipment outages (see Figure 4.1).

By contrast, LTE-based PPDR solutions can exhibit more abrupt failure modes. Because services run over commercial infrastructure and depend on multiple interconnected layers (including the RAN, core, device firmware, SIM profiles and mission-critical voice services), a single upstream issue such as a fibre break or a failure in a shared aggregation node can disconnect several sites simultaneously. In urban areas such as London, a single exchange may serve around ten mobile sites, meaning that an exchange-level failure can result in the loss of multiple sites in the same area at once. For users, this can lead to sudden loss of service or inconsistent behaviour, which is more challenging to manage during an unfolding incident (see Figure 4.1).

Figure 4.1: Network architecture and resilience of TETRA versus LTE



### 4.3.2 Confidence during high-risk operations

Responders rely on communication systems that behave consistently during dangerous or rapidly evolving situations. TETRA's performance in storms, power cuts and major incidents has created long-standing user trust. Its behaviour during degraded conditions is well understood. For example, during the EE network outage mentioned in Section 4.3.1, the commercial LTE-based network suffered a multi-site failure due to upstream faults, however, no outage was reported in the Airwave network, which remained fully operational.

LTE-based PPDR performance depends on the correct functioning of multiple interconnected layers (commercial radio equipment, PPDR core functions, priority rules, SIM/device settings and mission-critical voice services). Until these interactions are validated at scale under realistic load, there may be uncertainty about how LTE performs in the highest-risk scenarios.

### 4.3.3 Major incident performance

Major incidents require reliable group communication and rapid call set-up among many responders. TETRA is designed to maintain these behaviours even when large numbers of users are active.

LTE supports similar features through priority and pre-emption, but performance depends on consistent configuration across all network layers. During large events (for example, the Notting Hill Carnival, New Year's Eve celebrations, or other large-scale multi-agency public order deployments), any misconfiguration can lead to delayed call set-up or dropped calls. In addition,

the reliance on centralised network elements means that the loss of an exchange (for example, due to a fire or other site-level incident) may result in the simultaneous outage of multiple mobile sites in the affected area, potentially placing PPDR services at risk. ESN has also not yet been proven in a major unplanned incident, where no advance capacity planning is possible; by contrast, TETRA has a long operational record of remaining stable during sudden, high-pressure events, which is essential for Chief Constables when assessing readiness for mission-critical voice.

#### 4.3.4 Network congestion

In many situations, network congestion is caused by the public, not PPDR users. High public demand, such as live-streaming or heavy data use, can strain commercial networks.

Because LTE-based PPDR shares radio access with the general public, unexpected surges in demand can affect emergency-service performance unless priority and pre-emption rules are configured and applied consistently across the radio network, core, devices and applications. In practical terms, if prioritisation is not implemented correctly, a PPDR user responding to an incident may be competing for radio capacity with a child watching YouTube in the same cell sector, with the PPDR user's signal potentially degraded at a critical moment.

In addition, in LTE-based PPDR networks, priority and pre-emption mainly take effect once a device has successfully 'attached' to the network. If congestion is too severe, the network can become 'flooded' and there is a risk that the responder's device cannot complete its initial access and those priority features cannot yet be applied. Addressing this fundamentally would require ESN to operate over dedicated spectrum for mission-critical services, rather than relying on shared commercial radio access.

TETRA avoids these issues entirely as it already operates on dedicated PPDR-only spectrum with no exposure to public traffic.

#### 4.3.5 Redundancy from multiple radio bearers

Multiple radio bearer solutions (such as the aforementioned Dimetra Connect) allow devices to fall back to TETRA, LTE or Wi-Fi, while retaining the TETRA talkgroup model. This improves service continuity when radio conditions change or a specific bearer becomes unavailable, but still preserves familiar operational behaviour for users.

It is important, however, to recognise the limits of redundancy provided by mobile-only approaches. LTE-based redundancy typically relies on roaming or multi-operator SIM arrangements across commercial networks. While this may appear to offer diversity, in practice, different mobile operators often depend on shared or co-located exchanges, aggregation nodes, transmission routes and power infrastructure. As a result, failures at the exchange or backhaul level can affect multiple networks simultaneously, meaning that a secondary mobile bearer does not necessarily provide true independence or significantly improved resilience during major incidents.

From a resilience perspective, the most robust outcome (at least during the transition period) is therefore one in which TETRA and LTE play complementary roles rather than acting as substitutes. Maintaining TETRA as the primary carrier for mission-critical voice preserves access to a dedicated,

independent and proven communications layer. LTE can then augment this capability by supporting broadband data services and, where appropriate, acting as a secondary path for voice. This layered approach reduces systemic risk, protects continuity, and allows new capabilities to be introduced without compromising the reliability of core voice communications while LTE-based services continue to mature.

Overall, the evidence indicates that currently, TETRA provides a more consistent and predictable level of resilience for mission-critical voice than LTE-based PPDR solutions, which remain dependent on multiple commercial and technical layers that can introduce greater uncertainty during operational stress.

## 5 Special features

### 5.1 Special features comparison

TETRA provides two mission-critical capabilities: Direct Mode Operation (DMO) and ground-to-air communications. Both are mature, accredited and widely used across UK emergency services on a daily basis. These features work independently of network infrastructure and allow responders to maintain communication in locations or situations where coverage is poor, contested or unavailable. Because they are long-established and well understood, they offer predictable performance and give responders confidence during critical and time-sensitive operations.

LTE-based solutions aim to offer similar capabilities through 3GPP mission-critical features such as ProSe (sidelink) for device-to-device communication and LTE-based air-to-ground functions. However, these depend on newer standards that are still being adopted, require additional spectrum arrangements and aviation certification, and rely on device availability, chipset maturity and extensive operational testing. As a result, they are not yet operational at national scale and remain subject to external dependencies outside ESN's direct control.

During the ESN transition period and at present, TETRA remains the only operationally proven and fully trusted platform for direct mode and ground-to-air communications. It therefore acts as the default safety net when LTE-based features are unavailable, uncertified or still maturing.

### 5.2 Direct mode and ground-to-air communications features for TETRA versus ESN

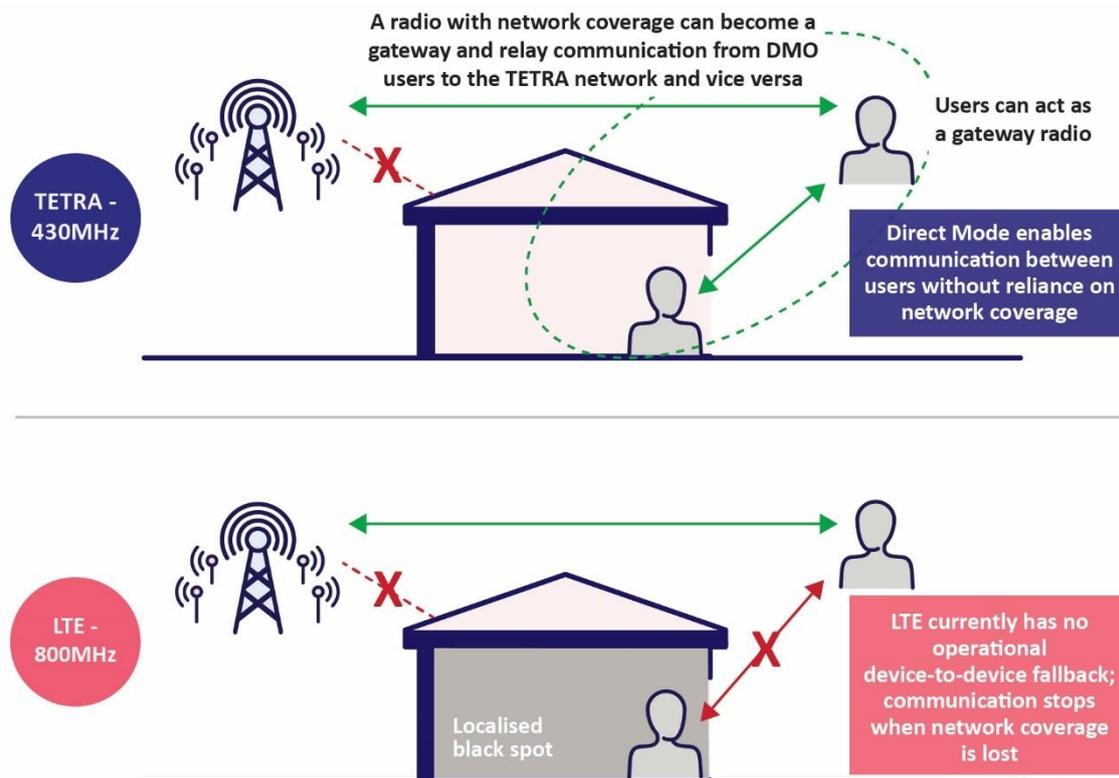
#### 5.2.1 Direct mode communications

##### *TETRA (DMO)*

TETRA enables radios to communicate directly with one another without relying on any network infrastructure. This capability is essential in locations where network coverage is weak or unavailable, such as inside buildings, tunnels, underground transport environments and remote rural areas. It is also relied upon during major incidents when infrastructure may be overloaded or damaged.

DMO includes additional functions that enhance operational flexibility. In repeater mode, one radio extends the range of others. In gateway mode, a radio with network access relays messages for users who are off-network (see Figure 5.1). These behaviours are long-established and familiar to responders, allowing communication to continue without requiring changes to existing workflows.

Figure 5.1: Illustration of DMO



### LTE (ProSe/sidelink)

LTE aims to provide a similar capability through ProSe, also known as sidelink. In practice, the delivery of ProSe depends on dedicated or synchronised spectrum, chipset and device support, stable power and timing control, interoperability across suppliers and UK-specific testing and certification. Although the feature exists in 3GPP standards, it has not yet been validated for UK operational LTE fallback. Current LTE devices used for ESN operate at relatively low transmit power (typically up to around 400 milliwatts (mW), as per 3GPP UE classes), which further limits off-network range compared with TETRA. As a result, when LTE coverage is unavailable, responders cannot rely on an LTE-based fallback and must use TETRA DMO to maintain communication. In practice, this means that responders who require assured off-network capability would still carry a TETRA device until LTE-based direct mode is fully validated for UK operational use.

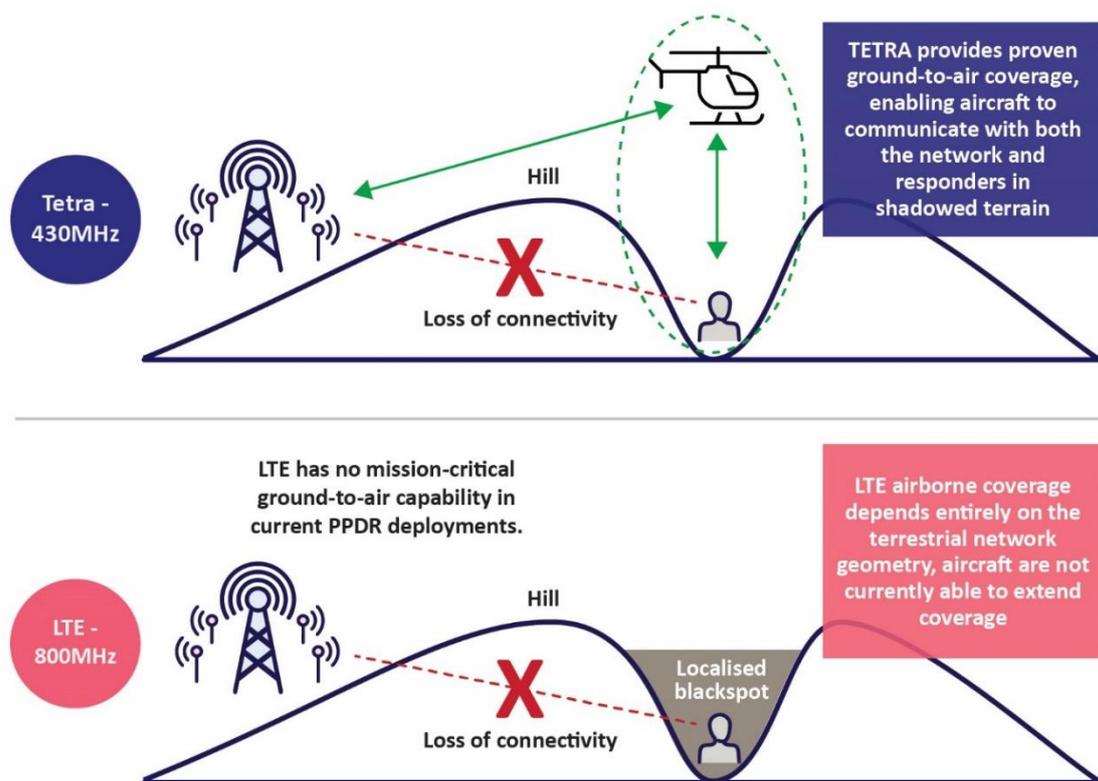
TETRA allows radios to communicate directly with each other without using any network infrastructure via DMO. This capability is crucial in situations where responders operate in areas with unreliable or no network coverage. TETRA portables routinely transmit at around 1 watt (W), and vehicle radios at 3W or more, giving materially stronger off-network performance and better propagation through buildings and terrain. Accordingly, TETRA is relied upon for direct mode communications today, as LTE-based alternatives depend on 3GPP features, device support and spectrum arrangements that are not yet operationally validated in the UK.

## 5.2.2 Ground-to-air communications

### TETRA

TETRA supports a fully operational ground-to-air capability used by police aviation units, the National Police Air Service (NPAS) and emergency helicopters. Its lower operating frequency enables wide-area coverage from altitude and supports reliable communication in areas where ground users may be in terrain shadow (see Figure 5.2). These capabilities are already fully operational, with predictable behaviour and well-understood coverage patterns. It integrates naturally with existing TETRA talkgroups and workflows, and is already certified and used routinely in live operations.

Figure 5.2: Illustration of ground-to-air communications



### LTE

ESN intends to introduce a future LTE-based air-to-ground capability. Delivering this depends on achieving aviation certification, co-ordinating spectrum for airborne use, ensuring device and chipset readiness, and integrating the service with mission-critical voice. These steps require co-ordination across aviation regulators, equipment suppliers and multiple agencies, which means operational readiness remains uncertain. Until these dependencies are fully resolved and validated, TETRA will continue to provide the assured solution for ground-to-air communications.

### 5.3 What it means for users

TETRA's DMO and ground-to-air capabilities are already embedded in daily PPDR operations across the UK. They behave consistently, require no additional set-up and are well understood by responders. Users rely on them in situations where communication is most at risk, like inside buildings and tunnels, for rural terrain, at major incidents and whenever network coverage is uncertain. These features have been validated repeatedly in real emergencies, which gives responders high confidence that communication will continue regardless of infrastructure conditions.

The LTE equivalents may ultimately provide broader functionality given their data transfer capabilities, but today they remain developmental, not yet certified for UK operational use and dependent on factors outside PPDR control, including spectrum alignment, device and chipset availability, and regulatory approvals for airborne use. This means performance may vary between devices, locations and operational contexts, and responders may need new training or workflows once these features are introduced as part of the PPDR devices. It is worth noting that the data transfer capabilities that ESN would offer are already used today for navigation, data access, multimedia reporting and similar tasks via separate commercial 4G/5G devices carried by PPDR operatives. Thus, the incremental operational benefit of ESN's LTE-based features will depend on their ability to match TETRA's reliability while offering genuinely enhanced capability once they are fully mature.

At present, at least during the ESN transition period (i.e. until the LTE-based features reach the same level of maturity and predictability), TETRA remains the assured safety net for device-to-device and ground-to-air communications. It provides responders with an immediate, dependable fallback in environments where LTE coverage is unavailable, contested or still maturing, ensuring continuity of mission-critical voice when it matters most.

## 6 Future of PPDR and continued need for TETRA networks

### 6.1 Future of PPDR

Airwave has been progressively modernised into a resilient, IP-based national network, and continues to deliver proven, mission-critical voice services – particularly group push-to-talk (PTT) – that remain unmatched in reliability and operational maturity by current commercial cellular solutions. International examples show that Airwave/TETRA and ESN-style LTE/5G networks are increasingly deployed in parallel as complementary systems, with TETRA envisaged to remain essential in the mid to long term, due to coverage, resilience and the complexity and risk of full migration.

#### 6.1.1 Airwave has been technically refreshed and modernised

Airwave operates on a modern, IP-centric network backbone. Although the service was originally deployed in the early 2000s, the underlying infrastructure has been progressively upgraded to support contemporary IP-based backhaul and core network functions, replacing legacy circuit-switched components. Modern network management, monitoring and control systems have also been integrated. As a result, Airwave's voice and short-data services are now delivered over resilient, managed IP transport networks, rather than relying solely on older, purpose-built radio switching technology.

Airwave has undergone equipment and software refresh cycles (in fact, the cycles are ongoing), including upgrades to base stations, switching elements and subscriber radios. These iterative enhancements have supported newer TETRA releases, strengthened network monitoring and redundancy, improved security, and ensured performance remains aligned with mission-critical voice and short-data requirements. Continued, routine investment in Airwave's infrastructure and operations will be required to ensure the network maintains the performance standards needed for mission-critical voice throughout the current contract period to 2029.

Airwave shares core technology characteristics with ESN, particularly the use of converged IP backhaul. Both networks ultimately rely on modern IP-based transport. Just as ESN operates over IP within a 4G/5G radio access and core network architecture, Airwave's backbone uses IP networking to interconnect sites, dispatch centres and control elements. This convergence demonstrates that Airwave's underlying transport infrastructure has evolved in line with contemporary network standards, supporting its long-term technical viability.

#### 6.1.2 Airwave provides proven mission-critical voice that will continue to remain essential

Voice communications remain the most critical life-saving service for emergency responders. While ESN aims to deliver voice, video and rich data using commercial networks, voice calls – especially group PTT – remain the highest priority in time-critical operations. TETRA was designed from the outset to deliver ultra-reliable mission-critical voice, including group calls with ultra-low set-up times, deterministic network behaviour under congestion, hard priority for emergency users, and resilience under load aligned to first-responder workflows.

These features do not yet have a like-for-like equivalent in commercial cellular PTT implementations. Even mission-critical voice (3GPP's mission-critical services standard) continues to be iterated, tested and integrated into national deployments. The continued reliance on Airwave by frontline services reflects its ongoing operational value and the proven reliability of its mission-critical voice capabilities.

### 6.1.3 Airwave and ESN are increasingly positioned as complementary, not redundant

Hybrid operations are becoming the practical transition model. Rather than treating TETRA and LTE as mutually exclusive, the emerging international trend is to operate both in parallel. The Airwave equivalent network continues to provide mission-critical voice with proven resilience and coverage, while the LTE network (and comparable broadband PPDR programmes abroad) adds broadband data, rich media and modern application ecosystems.

Some of the countries that have adopted a hybrid approach with both TETRA and mobile-based networks, at least for a potentially lengthy 'transitory period', include:

- **Germany:** in January 2026, Germany adopted a hybrid approach in which the nationwide BOS<sup>12</sup> TETRA network continues to provide mission-critical voice services, while a federal public-safety broadband network (4G/5G) is being developed to support data and future mission-critical services. Governance is shared between the federal level and the Länder (federal states). Both networks are expected to operate in parallel for a prolonged transition period, with TETRA remaining in service well into the 2030s while broadband capabilities are incrementally introduced and validated.
- **Finland:** in 2018, the Ministerial Committee on Economic Policy launched the 4G/5G-based Virve 2.0 project to initially complement the existing TETRA-based Virve network until at least the end of the migration period in 2028.
- **Italy:** in September 2022, the Italian Ministry of Interior awarded Telecom Italia Mobile a 3-year contract to provide an 4G-based public-safety service supporting mission-critical PTT voice, mobile video surveillance, database access and other critical broadband applications in 11 provinces, which complements Telecom Italia's existing national PPDR network.
- **Hungary:** in November 2022, a consortium led by Pro-M ZRT signed a contract to provide the 5G PPDR network in Hungary. This new network will have significant overlap with the existing TETRA-based PPDR network which will operate until at least 2035.
- **Sweden:** in February 2024, the Swedish Civil Contingencies Agency procured a 5G core network from Ericsson to develop Rakel G2, Sweden's critical communications network for public-safety and emergency services including national defence purposes, which will initially complement Rakel, the existing TETRA-based national radio communications system.

<sup>12</sup> BOS stands for *Behörden und Organisationen mit Sicherheitsaufgaben*, the umbrella term used in Germany for public-safety and security agencies, including the police, fire brigades and other public-safety authorities.

- **Denmark:** the SINE network (Denmark's national TETRA system) continues to provide mission-critical voice services, while the government is introducing 4G/5G public-safety broadband capabilities through commercial mobile networks. Denmark has explicitly adopted a hybrid model in which SINE is expected to remain the assured mission-critical voice bearer well into the 2030s, with broadband capabilities added incrementally for data-rich applications and situational awareness.
- **Luxembourg:** Luxembourg operates LUXTEL, a nationwide TETRA network used by emergency and security agencies. Broadband PPDR capabilities are being introduced via commercial 4G/5G services to support data, video and modern applications, complementing rather than replacing the TETRA system. Both networks are expected to operate in parallel for an extended transition period.
- **Saudi Arabia:** Saudi Arabia's Unified Secure Communications programme continues to rely on TETRA networks for mission-critical voice, while deploying a national PPDR broadband capability using 4G/5G and MCX services. The government has adopted a dual-network strategy in which TETRA will remain operational during a multi-year transition as broadband services are gradually expanded and validated.
- **USA:** the USA operates a hybrid model in which Project 25 (P25), the national mission-critical LMR standard analogous to TETRA, continues to provide voice services across federal, state and local agencies. In parallel, FirstNet delivers nationwide 4G/5G broadband for data, multimedia and situational-awareness applications. Both networks are expected to operate concurrently for the long term, with P25 retained as the primary mission-critical voice bearer.

While it is theoretically possible to emulate TETRA's coverage and indoor penetration using low-frequency 4G (for example, the Czech Republic's use of Nordic Telecom), such examples remain rare and are not operationally proven. This reflects limited commercial incentives for mobile operators to deploy dedicated low-frequency broadband networks solely for PPDR when a TETRA network is already in place. As both coverage and resilience are fundamental to emergency communications, running TETRA alongside emerging broadband networks often provides greater operational confidence.

## 6.2 Future of TETRA

It should also be noted that while many countries are running a TETRA network alongside 4G and 5G networks, the 'switch-off' date for TETRA remains uncertain (i.e. it is an open question). In addition, the dates are set as a goal, rather than fixed deadlines. As has already been demonstrated, goals associated with TETRA switch-off tend to slip significantly: therefore, even countries such as Norway and Sweden, which have a switch-off goal of 'around 2030', may see that extended into the next decade.

Norway still has to undergo a market engagement and procurement process, followed by a business case (financing) evaluation and quality assurance processes before contracts can be awarded, which was forecast to be by the end of 2025. The network build, including end-user transfer, is assumed to take approximately two years, which is forecast to start in 2028 and finish by 2030. As all of these activities face a high chance of significant delays, Analysys Mason believes that the quoted 2030 timeframe appears to be very ambitious.

Meanwhile, in Sweden, the user community is understood to also be very concerned about the level of service provided. Users have identified that the bottleneck lies less with the network and more with the major IT transformation and operating-procedure changes required across control rooms, applications, devices and user workflows. No publicly available reports have been found that set out an ESN-specific, end-to-end mapping of these operational and IT changes for the UK. By contrast, Sweden's Rakel G2/SWEN programme explicitly treats migration as both a technical and organisational transformation, with user-practice changes planned alongside the introduction of the new 5G-based network.

### ***Satellite as a complementary bearer***

LEO satellite connectivity, including services such as Starlink, is being explored within ESN as a potential supplementary bearer for backhaul or situational data in remote or infrastructure-degraded environments. Satellite links can provide temporary connectivity in locations where terrestrial capacity is unavailable, and may offer an additional contingency pathway in major incidents. However, satellite systems do not address many of the coverage challenges that are most relevant to PPDR operations. Indoor environments, dense urban areas, basements and tunnels lack reliable line-of-sight to the sky, meaning availability is often unpredictable for frontline responders. As a result, satellite connectivity cannot mitigate the core terrestrial coverage issues described earlier in this report. In addition, some LEO satellite services (including Starlink) are operated by non-UK sovereign entities, meaning service continuity may be influenced by external commercial, regulatory or geopolitical factors beyond the UK's control.

From a resilience perspective, LEO satellite performance can vary with environmental conditions, terminal placement and network loading, and has not yet been proven in routine PPDR operations at national scale. Satellite platforms have also experienced systemic outages, including a widely reported global Starlink outage of approximately 2.5 hours in July 2025,<sup>13</sup> underscoring that they do not currently deliver the predictable resilience required for mission-critical voice. Satellite services also do not provide the special features relied upon by emergency services today, such as DMO, group-based communications or deterministic call behaviour under congestion. Furthermore, space-segment and ground-segment assets introduce additional attack surfaces, including susceptibility to cyber interference, signal jamming or orbital disruption.

Overall, satellite connectivity is best viewed as a complementary capability, primarily suited to data and exceptional contingency scenarios. It should not be relied upon to provide assured nationwide coverage or to close terrestrial coverage gaps, and does not remove operational uncertainty for users unless integrated within a wider multi-bearer architecture.

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<sup>13</sup> [Forbes \(2025\), Starlink Down – What Caused The Global Outage And Is It Back Up Yet?](#)

## 7 Conclusion

This paper shows that, for the foreseeable future, TETRA remains the benchmark for mission-critical voice communications in PPDR operations. Its coverage, resilience and operational behaviour are well understood, predictable and proven in the environments where emergency responders operate. While LTE-based solutions (such as the UK's ESN) offer clear potential for data services, their readiness for mission-critical voice remains constrained by coverage variability, evolving features and delivery timelines that are still subject to change.

As a result, maintaining TETRA – including both the radio network and its associated command-and-control systems, alongside the continued development of LTE/5G for data services and multi-bearer resilience – represents the most effective approach to safeguarding service continuity, operational resilience and user confidence. This remains essential even as emerging technologies such as LEO satellite links are explored as supplementary bearers, as these do not replace the need for predictable, terrestrial mission-critical voice. The evidence indicates that a measured, hybrid approach, which preserves proven voice capabilities while gradually integrating new broadband services as they mature, provides the most robust path forward. Ensuring uninterrupted access to reliable and predictable voice communications must therefore remain central to the UK's PPDR communications strategy.