communications

Evolution of TETRA

To a 4G All-IP Broadband Mission Critical Voice Plus Data Professional Mobile Radio Technology

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1 MANAGEMENT SUMMARY

While LTE is becoming the predominant global commercial mobile radio technology, the professional mobile radio industry including the TETRA industry is at a crossroads to decide the direction of standardization and product development for at least the next decade.

This white paper proposes an evolutionary path from TETRA 1 to TETRA 3. In order to point out the main differences between commercial and professional mobile radio, the four key requirements for mission critical communication have been defined in section 2.1. After having looked back to the history of mobile radio evolution in section 2.2, it is made clear in section 2.3 that a future broadband PMR standard should be based on LTE and that LTE will not become mission critical unless the PMR industry refines LTE for mission critical use. It is proposed to give mission critical LTE the name TETRA 3, because TETRA is the technologically most advanced PMR standard with the largest installed base worldwide.

Having learned from the shortcomings of standardizing narrowband PMR systems, see section 2.4, and having assessed the capabilities of LTE, the following key requirements for TETRA 3 are specified in section 2.5:

- Harmonised broadband frequency spectrum for PMR use (at least 2 · 5 MHz);
- reuse of LTE reference points for the infrastructure enabling multi-vendor markets for network elements and allowing for low latency infrastructures;
- development of dedicated broadband PMR encryption algorithms for user-to-network security and end-to-end encryption;
- standardization of a broadband control room API;
- broadband direct access;
- intra-system handover with TETRA 1 and TETRA 2;
- interworking with P25 and TETRAPOL;
- inter-system IP unicast and multicast (broadband cross-border packet data);
- traffic load dependent energy economy mode for idle base stations.

Finally, section 2.6 points out that migration to TETRA 3 first requires migration to TETRA 2 in order to provide higher than narrowband data rates for mission critical packet data to PMR users before 2020 and to offer the TETRA industry the incentive to continue improving professional mobile radio. This white paper ends with a proposed phasing of TETRA 3 towards a 4G all-IP broadband mission critical voice plus data professional mobile radio technology.

2 EVOLUTION OF TETRA

2.1 Definition of mission critical communication

A mobile radio communication system must fulfil four key requirements in order to be usable for mission critical communication:

1. **The infrastructure must be resilient and highly available.**
   This is normally achieved with the help of a redundant network architecture, redundant links between network elements and fail-safe network elements. Furthermore, base stations can increase the availability of their cells by operating in a fallback mode and by providing a minimum service when the connection to the infrastructure gets lost and when network wide services cannot temporarily be supported.
2. **Communication must be reliable.**
   In a mission critical network communication services have to be accessible and stable, i.e. network capacity has to be available even in case of large scale disaster scenarios. Furthermore, individual and group calls have to be setup in a predefined and extremely low time, e.g. 500 ms. Even at cell edge, speech packets, short data messages and packet data have to be reliably transferred to the end user.
3. **Communication must be secure.**
   A mission critical network provides security functions in order to protect users from jamming, interception, and spoofing:
   - mutual authentication of infrastructure and terminals;
   - methods for temporarily and permanently disabling terminals and smart cards;
   - functions to detect and compensate for jamming at the air interface;
   - air interface encryption of user data and signalling data including addresses;
   - end-to-end encryption of user data.
4. **Point-to-multipoint communication shall be supported.**
   Professional users mainly operate in groups. This is why, a mission critical network has to support point-to-multipoint communication, i.e. group calls, group addressed short data messages and group addressed packet data.

If a mobile radio communication system does not fulfil the above four 'mission critical' requirements completely, then it can only be used for business critical communication. In general, commercial mobile radio networks are only capable of supporting business critical communication.

Due to the fact that TETRA complies with the four 'mission critical' requirements above, TETRA provides a narrowband and wideband mission critical voice plus data mobile radio technology for PMR users mainly belonging to the sectors PPDR, utilities, and transportation.

2.2 History of mobile radio evolution

Also in the future, it will be necessary to develop professional mobile radio standards on the basis of commercial mobile radio standards. The reason for this lies in the fact that manufacturers and operators of commercial mobile radio networks have almost no commercial interest in enhancing their products and networks for a small user group with extremely challenging requirements. On the other hand, PMR manufacturers cannot afford several billion euro research and development budgets to develop next generation PMR mobile radio technologies in parallel to or even ahead of commercial mobile radio manufacturers. This is why, downstream mission critical refinement of new commercial mobile radio technologies seems to be the “natural law” of PMR research and development.

One example illustrates the different dimensions of the niche PMR market and the commercial mobile radio market. Considering all existing PMR technologies worldwide, not more than 40 million PMR terminals are currently in use. On the opposite, if a major commercial mobile phone manufacturer sold only 40 million mobile phones in the most recent quarter, then this company would have to face severe downgrading by international rating agencies.

As depicted in Figure 1, TETRA 1 followed GSM and refined GSM for mission critical communication. TETRA 2 reused the packet data service of GPRS and the adaptive modulation techniques of EDGE. Due to PMR users only slowly adapting to technological innovations, e.g. not all countries in Europe including Germany have complete nationwide PMR networks in operation, PMR manufacturers hesitated to adopt 3G technologies into TETRA or any other PMR standard. Unlike the evolution of commercial mobile radio standards, which is mainly driven by innovations of manufacturers, the evolution of TETRA is almost only driven by requirements of PMR users, especially of PPDR users. This is why, the Working Group 1 “TETRA User Requirements and Services” is an essential part of the standardisation body within ETSI responsible for TETRA, i.e. TC TETRA, and the Operators and Users Association as a group within the TETRA + Critical Communications Association defines the use cases of services to be later implemented and tested by TETRA manufactures.

Most recently, PMR users have started to identify user requirements for broadband mission critical data applications which include transfer of location data, multimedia video and photo transfer, office applications, upload and download of operational information and online database enquiries.

As a consequence of this, ETSI TC TETRA has initiated a new work item to expand the TETRA standard for transfer of broadband packet data which is scheduled until the end of 2016. The scope of this work item is yet unclear. Even the whole TETRA industry is extremely uncertain in the moment whether TETRA is already a legacy technology and will shortly be replaced by mission critical LTE.

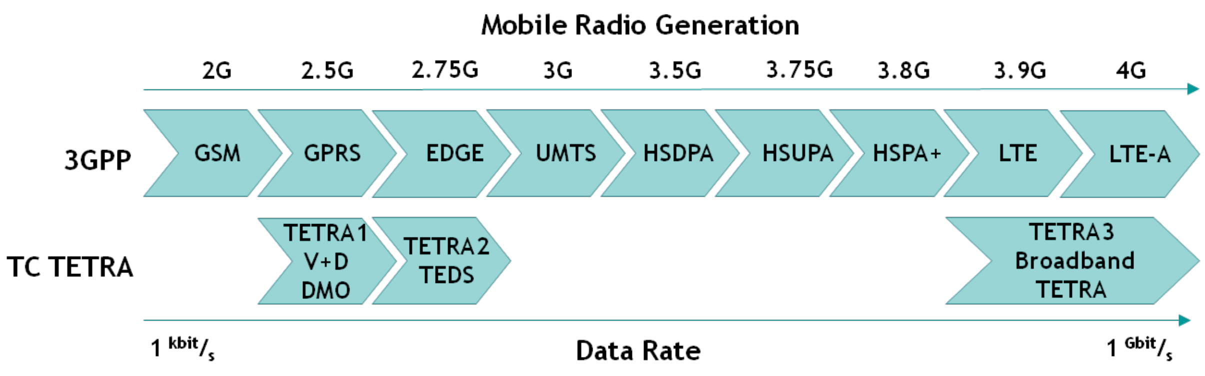


Figure 1: Mapping of commercial business critical mobile radio standards to professional mission critical TETRA

The next evolution of commercial mobile radio networks (3.9G and 4G) will provide broadband and low latency services and offer a compelling business proposition for operators, enabling a smooth migration path, flexible spectrum bandwidth, and the ability to deliver low cost per bit voice and data services. LTE will offer the ability to interconnect with other access technologies, hence allowing operators to converge their fixed line broadband networks and to deliver seamless communication to end users.

It is the goal of this white paper to outline a highly probable evolutionary path towards a mission critical broadband PMR standard, an evolutionary path towards TETRA 3.

2.3 Why TETRA over LTE will not work and why LTE will not become mission critical

Obviously, it can be derived from Figure 1 that any future PMR broadband technology will be based upon LTE and LTE-A. The United States and Canada already officially committed to LTE for public safety communication. According to the IMT-Advanced definition of requirements for a 4G mobile radio technology, LTE-A is a candidate for a 4G technology, but LTE is not. Amongst other requirements, a 4G technology has to provide a data rate of 1 $^{Gbit}/_{s}$ in a stationary environment and of 100 $^{Mbit}/_{s}$ in a highly mobile environment. LTE is clearly not capable of fulfilling these 4G requirements.

Considering the definition of mission critical communication given above in section 2.1, LTE will support reliable data communication and point-to-multipoint data communication with the help of the evolved Multimedia Broadcast and Multicast Service (eMBMS). On the other hand, LTE does not support individual calls and group calls with a quality needed by PMR users.

The LTE security architecture provides procedures for user-to-network security and, additionally, the IMS media plane supports end-to-end encryption. The TETRA security procedures such as air interface encryption and end-to-end encryption use special encryption algorithms which are considered to be dual-use technologies and which are subject to export control. If LTE is to support mission critical broadband data communication, then LTE has to be adapted to support new encryption algorithms for user-to-network security and for end-to-end encryption only to be used by PMR users.

It is very unlikely that LTE or LTE-A will become mission critical because there is no commercial interest to standardise and implement new encryption algorithms only needed by a small user group. Furthermore, commercial LTE and LTE-A networks will not be as highly available as needed for nationwide PPDR operation. Consequently, if a TETRA application would be run over a commercial LTE network, such an application could not be used for mission critical communication, because the LTE network operator would have no commercial interest to invest in five nines availability (99,999 %) typically required for mission critical networks.

2.4 How to avoid repeating the shortcomings of PMR narrowband system standardization?

Looking back to TETRA standardization since 1990, two major shortcomings can be identified:

1. The TETRA industry was not able to agree upon a reference architecture for the TETRA Switching and Management Infrastructure (SwMI). No reference points and no interfaces between network elements have been standardized which prohibited multi-vendor markets within nationwide infrastructures.
   The evolved packet core (EPC) of LTE has been highly optimized to support low latencies. An LTE based Broadband TETRA system will only be able to support mission critical broadband video applications with a real time quality of service (QoS), if TETRA 3 reuses LTE reference points within the infrastructure. As a consequence of this, the TETRA 3 market should be a pure multi-vendor market for terminals, control rooms – and network elements. LTE reference points within a TETRA 3 infrastructure also ensure that TETRA 3 infrastructures are prepared to easily benefit from LTE evolving to LTE-A or even 5G.
2. No control room interface has been standardized. This is why, all TETRA infrastructure manufacturers provide proprietary APIs for control rooms and the TETRA + Critical Communications Association does not test and certify the interoperability of control rooms, although control rooms are essential in daily PMR operations.
   TETRA 3 should specify a broadband data API for control rooms, which provides access to end-to-end encrypted broadband packet data and, furthermore, allows for user management, network management and network monitoring.

2.5 Requirements for a 4G broadband PMR technology

The regulatory body of the United States, the FCC, has identified 2 · 5 MHz of frequency spectrum in the 700 MHz frequency band for broadband public safety communications (763 MHz-768 MHz and 793 MHz-798 MHz). Most probably, harmonized frequency spectrum for broadband public safety communications in Europe will not exceed 2 · 5 MHz, too. As shown in Table 1, peak data rates of an LTE based PMR system with 2 · 5 MHz of frequency spectrum would not exceed 73 $^{Mbit}/_{s}$ on the downlink and 18 $^{Mbit}/_{s}$ on the uplink. Average achievable IP throughput will be significantly lower and definitely far away from 4G data rates. Unlike commercial LTE networks designed for broadband download, the upload of broadband operational information in a future TETRA 3 system will be a predominant use case. It can be anticipated that the uplink will be the bottleneck of future broadband PMR systems.

Table 1: LTE peak data rates

Bandwidth	(MHz)	1.4	3	5	10	15	20
Downlink	($^{kbit}/_{s}$)	17,520	44,304	73,392	150,752	220,272	299,552
Uplink	($^{kbit}/_{s}$)	4,392	11,064	18,336	36,696	55,056	75,376

Due to LTE-A providing higher data rates on the uplink (design goal: 500 $^{Mbit}/_{s}$) and new procedures for better coverage with the help of relay nodes and for interference avoidance such as distance based frequency reuse, this uplink bottleneck will not be resolved before the successor of LTE has been adapted to mission critical communication.

TETRA is the technologically most advanced PMR standard with the largest installed base worldwide. Therefore, an LTE based broadband PMR standard should be an expansion of TETRA and should provide both, broadband direct access and intra-system handover to TETRA 1 and TETRA 2. Nevertheless, TETRA 3 should allow for interworking with P25 and TETRAPOL.

Although the last north-atlantic public safety partnership between the standardization bodies TIA and ETSI in the project MESA did not yield to any products, a globally harmonized broadband PMR standard should be achievable. In contrast to narrowband PMR standardization and considering the increased complexity of 4G, manufacturers will not be able to afford developing broadband mission critical products based on regional standards. Resolving concerns with regard to the export control of encryption algorithms will surely be a major challenge of such a standardization effort.

One aspect mostly neglected so far in mobile radio networks is power consumption of the infrastructure. Nationwide PMR networks have to cover rural areas commercial network operators are not interested in. Normally, traffic load in rural areas is quite low leading to idle phases of base stations. The overall power consumption of a PMR network could be significantly reduced by introducing a traffic load dependent energy economy mode for idle base stations.

2.6 Migration to TETRA 3

Starting from 2020, a broadband data PMR standard will be fully specified and published, harmonized spectrum for broadband PMR use will be allocated, broadband PMR products will be mature and nationwide broadband PMR roll-outs will be almost completed.

It is crucial for TETRA evolution that nationwide TETRA operators first invest into TETRA 2 before upgrading to TETRA 3. In October 2011, TEDS Direct Access has been published by ETSI TC TETRA as a new milestone of TETRA evolution completing several years of standardization and product development. Due to the “natural law” of downstream mission critical refinement of new commercial mobile radio technologies as mentioned in section 2.2, pure 4G commercial LTE-A networks with 1 $^{\text{Gbit}}/_{\text{s}}$ data rates will most probably be in operation by 2020, when not yet 4G LTE based PMR networks are to be rolled-out. If TETRA operators decided not to invest in TEDS today, because a future broadband PMR solution will provide much higher data rates, then the same constellation would occur again when an LTE based PMR solution has to compete with commercial LTE-A implementations. TETRA manufacturers would have to evaluate the risk whether to invest in standardization and product development for an LTE based PMR solution which customers most likely will consider to be outdated when completed. If TEDS becomes a business failure, then major TETRA manufacturers might quit the TETRA business and will only continue to maintain their installed base. In such a case operators and users would have to face the following situation:

- TETRA would become a legacy technology,
- only narrowband mission critical data transfer would be available until the end of this decade,
- mission critical voice services would not be standardized and implemented and, thus, no replacement for TETRA 1 systems would be available in the next decade.

On the other hand, if TETRA operators and users invested into TEDS, then TETRA would continue to exist and wideband mission critical packet data would provide data rates of about 100 $^{kbit}/_{s}$ and would cover the major part of existing user requirements for packet data. It has to be mentioned that harmonized frequency spectrum for wideband packet data (most probably 2 · 1,5 MHz in the 400 MHz frequency band) still has to be allocated by regulatory bodies. Once a broadband TETRA 3 network is deployed, a nationwide wideband TEDS packet data network could be used as a fallback in areas without broadband coverage.

Evolution from TETRA 1 to TETRA 3 via TETRA 2 only makes sense, if the introduction of TETRA 2 is used to prepare existing networks for TETRA 3, i.e. the radio access network and the core network have to become all-IP while maintaining the challenging quality of service of mission critical circuit mode voice services.

The following evolutionary phases can be anticipated for standardizing and implementing TETRA 3 as a 4G all-IP broadband mission critical voice plus data professional mobile radio technology:

TETRA 3 Phase 1 (2020): 3.9G LTE based TETRA 3 broadband mission critical packet data

- Harmonized broadband frequency spectrum for PMR use;
- reuse of LTE reference points for the infrastructure enabling multi-vendor markets for network elements and allowing for low latency infrastructures;
- development of dedicated broadband PMR encryption algorithms for user-to-network security and end-to-end encryption;
- standardization of a broadband control room API;
- broadband direct access;
- intra-system handover with TETRA 1 and TETRA 2;
- interworking with P25 and TETRAPOL;
- inter-system IP unicast and multicast (broadband cross-border packet data);
- traffic load dependent energy economy mode for idle base stations;
- roll-out of TETRA 3 in hot spots mostly reusing existing sites with a network architecture guaranteeing resilience and high availability;

TETRA 3 Phase 2 (2024): 4G LTE-A based TETRA 3 broadband mission critical packet data

- 4G data rates for mission critical packet data;
- nationwide coverage with the help of TETRA 3 relay nodes;

TETRA 3 Phase 3 (2028): 4G LTE-A based TETRA 3 broadband mission critical voice plus data

- IP Multimedia Subsystem based mission critical point-to-point and point-to-multipoint voice services with guaranteed quality of service on a nationwide level and for inter-system communication;
- Phase 3 completely replaces TETRA 1, TETRA 2, P25 and TETRAPOL networks.

ABBREVIATIONS

3GPP	3rd Generation Partnership Project
EDGE	Enhanced Data Rates for GSM Evolution
EPC	Evolved Packet Core
ETSI	European Telecommunications Standards Institute
eMBMS	evolved Multimedia Broadcast and Multicast Service
FCC	Federal Communications Commission
GSM	Global System for Mobile Communications
GPRS	General Packet Radio Service
HSDPA	High Speed Downlink Packet Access
HSUPA	High Speed Uplink Packet Access
HSPA+	High Speed Packet Access Plus
IEEE	Institute of Electrical and Electronics Engineers
IMS	IP Multimedia Subsystem
IMT	International Mobile Telecommunications
IP	Internet Protocol
LTE	Long Term Evolution
LTE-A	Long Term Evolution – Advanced
MESA	Mobility for Emergency and Safety Applications
P25	Project 25
PMR	Professional Mobile Radio
PPDR	Public Protection and Disaster Relief
QoS	Quality of Service
SwMI	Switching and Management Infrastructure
TC	Technical Committee
TEDS	TETRA Enhanced Data Service
TETRA	Terrestrial Trunked Radio
TIA	Telecommunications Industry Association
UMTS	Universal Mobile Telecommunications System
VDE	Verband der Elektrotechnik Elektronik Informationstechnik e. V.

ABOUT

P3 communications GmbH

The P3 group is an engineering company and professional service provider with more than 1,000 engineers and computer scientists for the automotive, aviation and telecommunication industries. Headquarter of P3 is in Aachen, Germany with local offices in all major European countries as well as in the USA and India. Since 2004, P3 communications consults German governmental bodies responsible for planning, engineering, procuring, integrating and operating the forthcoming world's largest critical communications TETRA network for public safety users throughout Germany.

Dr.-Ing. Martin Steppler

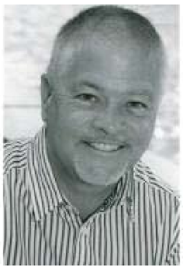
Dr. Steppler (⋆1969) has been involved in TETRA since 1993 and received a Master of Science and a Ph.D. degree in electrical engineering from RWTH Aachen University in Germany, both for publications on TETRA. Since 1999, he has been consulting governmental bodies with regard to the nationwide TETRA network in Germany. Dr. Steppler actively participates in the work of the standardization bodies within ETSI TC TETRA and TETRA + Critical Communications Association. Dr. Steppler is a personal member of IEEE and VDE.

Dr.-Ing. Peter Sievering

Dr. Sievering (⋆1973) is experienced in performance evaluation of ETSI broadband radio access networks and has contributed to project MESA. He received a Master of Science and a Ph.D. degree in electrical engineering from RWTH Aachen University in Germany and has published several papers on TETRA, including his Ph.D. thesis. Since 1999, Dr. Sievering offers technical and strategic consulting services as well as planning and engineering services for governmental bodies with regard to the nationwide TETRA network in Germany.

Dipl.-Ing. Stephan Kerkhoff

Stephan Kerkhoff (⋆1967) has more than 15 years experience in mobile communications. He received a Master of Science degree in electrical engineering from Ruhr-University Bochum. Since 1993, he has been involved in network planning, with main focus on strategy and network evolution. Since 2007, Mr. Kerkhoff offers consulting services for governmental bodies with regard to the nationwide TETRA network in Germany.



Tony Gray

Tony Gray's (⋆1955) career in critical communications & control systems spans some 35 years, much of which he has spent engineering and consulting on technology standards such as TETRA and their application to mission-critical solutions in a variety of markets worldwide.