Using TETRA for Remote Control, Supervision and Electricity Metering in an Electric Power Distribution System

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Abstract: An important part of the communication infrastructure in systems that cover large geographic areas and require maintenance and management of devices on remote locations - such as electric power distribution systems - is mobile radio communication. This is especially important on remote locations with no other communication means available. Besides the traditional voice communication, the new digital PMR systems also support various modes of data communication including the IP protocol. This offers new possibilities for remote data applications. In our paper, the possibilities of using a TETRA system for remote data applications such as remote control and supervision of breakers and disconnectors, and remote electric meter reading, are analyzed for the case of the electric power distribution company Elektro Ljubljana, d.d.

Key-Words: electric power distribution, remote metering, automated circuit breakers, PMR, TETRA

1 Introduction

Special professional radio communication systems, known as Professional Mobile Radio (PMR), have been developed for use in organizations requiring reliable wireless communication. Initially, these were analog systems intended primarily for voice communication but also with some limited data communication capabilities. Analog systems are now being replaced by new digital PMR systems, which, besides better voice services, offer additional data communication services, opening new possibilities for data applications.

Fig. 1: Map of Slovenia and Elektro Ljubljana

In this paper we analyze the possible use of the PMR system TETRA for data communication in an electric power distribution company. Applications such as remote control and supervision of the distribution network equipment and remote electric meter reading are presented for the case of Elektro Ljubljana, which serves about 300.000 consumers and is the largest of the five Slovenian electric power distribution companies, each covering a particular geographical region of Slovenia (Figure 1).

2 Digital PMR systems

Wireless radio communications form an indispensable part of the communications infrastructure in organizations and enterprises that need to communicate with individuals or groups working in the field, and where other means of communication (especially fixed wired links) are neither suitable nor available. Nowadays, public mobile phone systems like GSM are available everywhere and are often used also for professional work, including remote control and monitoring of power electric equipment and other devices [1, 2]. However, public communication systems are only partially usable in critical operation since they have not been designed for reliable operation in emergency situations. In such circumstances, when they are most needed, they are likely to fail, partly due to overloading by public communication traffic (voice calls). For reliable professional use, special Professional Mobile Radio (PMR) systems have been developed. The existing analog variants are being superseded by new digital ones. Their important features encompass high reliability of operation, fast call setup (e.g. 0,3 s in the case of TETRA), secure communication with authentication and speech encryption, group calls and conversations, priority assignments and management for different classes of calls, including emergency calls with the highest priority, dispatcher support (typical connections are between a remote user and a dispatcher), direct mode of communication between mobile/handheld stations without a base station, independent local operation of a base station in cases of main switch failure or inaccessibility, a mobile station working as a repeater to connect users at a location not directly covered by a base station signal, etc. Modern PMR systems also support data transmission including the IP protocol.

A number of different PMR systems have been developed in different parts of the world [3, 4]:

- Project 25 (USA)
- TETRA (Europe)
- IDRA (Japan)
- DIMRS (Canada, known also as iDEN)
- TETRAPOL (Europe)
- EDACS (USA)
- FHMA (Israel).

Two systems have been developed (and are used) in Europe - TETRA and TETRAPOL [5, 6, 7, 8]. Table 1 summarizes key technical properties of these two systems and the new USA system Project 25 [9].

TETRA (TErrestrial Trunked RAdio system) has an advantage over TETRAPOL in that it is based on independent public ETSI standards (European Telecommunications Standards Institute, http://www.etsi.org) [10] and is supported by a number of equipment manufacturers, while TETRAPOL has been developed by the French company Matra with the equipment now being produced by EADS. Although TETRA is the more recent system (the first installation in 1997), it is much more widely used.

Table 1: Technical characteristics - TETRA, TETRAPOL and Project 25

	TETRA	TETRAPOL	Project 25
Max TX power (W)			
- base station	25	25	500
- mobile station	10 (average 2,5)	10	10 do 110
- handheld station	1 (average 0,25)	2	1 do 5
Cell radius (km)	3,8-17,5	8-28	7,6-35
- handheld/suburb	3,8	8	7,6
- mobile/rural	17,5	28	35
No. of channels/RF carrier	4	1	1
Access method	TDMA	FDMA	FDMA
RF carrier spacing (kHz)	25	12,5 / 10	12,5 (C4FM) 6,25 (CQPSK)
Modulation	π/4 DQPSK	GMSK	QPSK family: C4FM, CQPSK
Communication speed (kbit/s)	36	8	9,6
Speech codec	ACELP	RPCELP	IMBE
Bit rate (kbit/s)	4,567	6	4,4
With error protection	7,2	8	7,2
Data transmission (kbit/s)			
- protected	do 19,2 (4x 4,8)	3,2	6,1
- unprotected	do 28,8 (4x 7,2)	7,6	9,6

3 TETRA

In this section, a short overview of the TETRA PMR system is given, with a description of the data communication services supported, and radio signal coverage.

3.1 Technical overview

A TETRA system consists of one or more switches, one or more dispatch centres, base stations on fixed locations with good radio signal coverage, and user terminals (handheld and mobile radio stations). The system can be connected with other communication systems like wired and wireless phone systems and data communication systems with IP protocol. Figure 2 depicts a simple TETRA system with a single switch and a single dispatch centre (such a system would meet the needs of a single organization on the territory of Slovenia).

TETRA, like other modern digital PMR systems, supports virtual networks, enabling a number of independent users (organizations, enterprises) to share a common communication infrastructure (switches, base stations, etc.) while maintaining their communications virtually separated from each other. Infrastructure management is common and can be performed by a common body or an independent commercial TETRA network provider. In this way, investment and maintenance expenses for each user are much reduced.

The TETRA standard defines operation on radio frequencies 300-1000 MHz. The equipment is produced for existing PMR frequency bands, i.e. around 400 MHz for Europe and some other countries, and 800 MHz for the USA and some other countries.

Each RF channel is 25 kHz wide and carries four communication channels using Time Division Multiple Access (TDMA), as shown in Figure 3 (where one communication channel is used for a voice call, another for a fax call, and two channels are grouped together for IP data communication.) One communication channel on each base station is reserved for use as a control channel (call setup, message transmission, etc.). The system uses Frequency Division Duplex (FDD), enabling full duplex communication.

3.2 Data transmission

TETRA supports different data communication modes that that can be used for a variety of data applications [11, 12, 13]. A communication channel can carry a circuit-switched link or packet data communication, normally with the IP communication protocol. Table 2 summarizes transmission speeds achievable over a single communication channel.

Table 2: TETRA data transmission speed (single channel)

Error protection level	Data rate [kb/s]
No protection	7,2
Normal	4,8
High	2,4

Up to 4 communication channels can be aggregated to achieve a correspondingly higher transmission speed (up to four times), but also with correspondingly higher consumption of

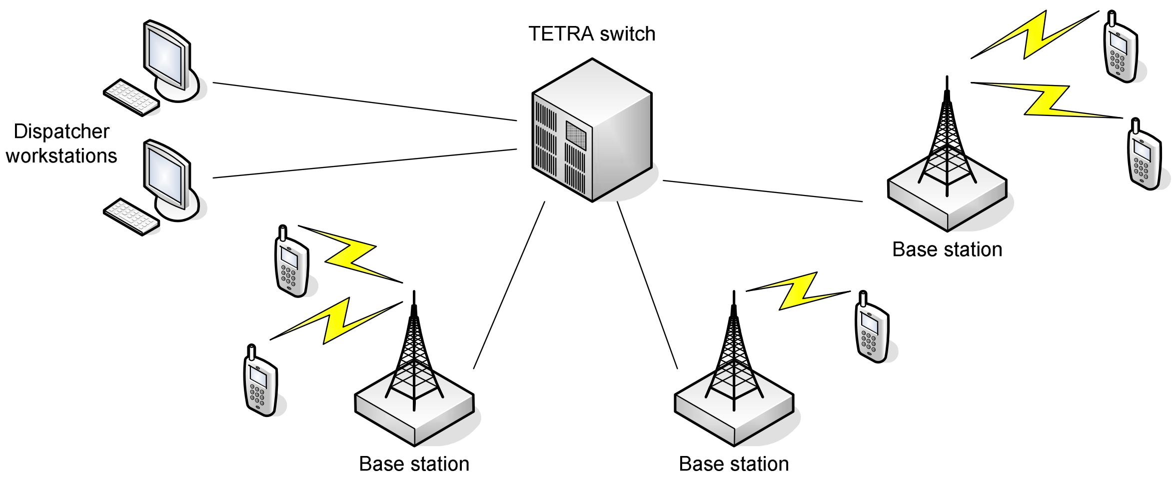

Fig. 2: A simple TETRA system

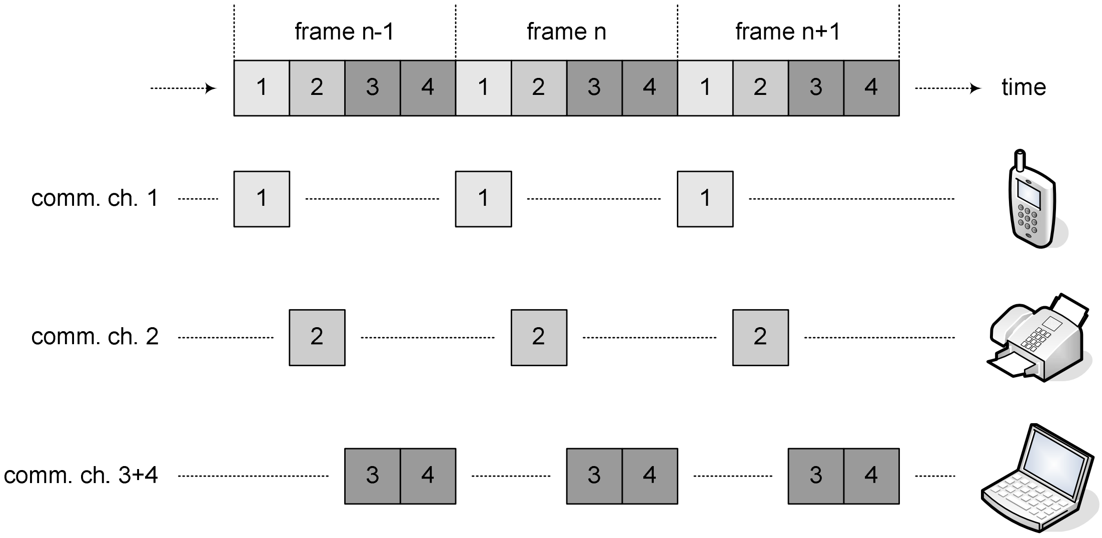

Fig. 3: Time Division Multiple Access in TETRA

communication resources (channels) and power in the mobile/handheld terminal. A TETRA terminal equipped with appropriate embedded software can be used as a WAP terminal, or as a modem for connecting a laptop computer or other data device to an IP network (e.g. Internet) over the TETRA network.

Another mode of data communication is SDS (Short Data Service), used for transmission of short status and user messages. It transfers data using the system control channel and is suitable for simple transfer of small quantities of data. Different types of user message exist for transferring either fixed-length 2-, 4-, or 8-byte, or variable length messages (up to around 255 bytes).

TETRA terminals have a standard interface for connecting user data equipment. This is (as in the case of dial-up modems or GSM mobiles) an asynchronous serial line with the AT command support.

Table 3: Modulations and transmission speeds (25-kHz RF channel)

Modulation	Data rate [kb/s]
π/4 DQPSK	36
π/8 D8PSK	54
4 QAM	38
16 QAM	77
64 QAM	115

TETRA data transmission rates are adequate for applications like WAP, textual messages, and also transmission of small compressed pictures. Multimedia contents require a higher transmission speed, which the next generation (TETRA version 2) will provide, using TEDS (TETRA Enhanced Data Services). Modulation types and related achievable data transmission speeds in a 25 kHz RF channel are listed in Table 3. They depend on the quality and power of the received signal and hence on the distance and terrain configuration between a user terminal and a base station.

TEDS also defines wider RF channels (50, 100 and 150 kHz – QAM modulation only), offering correspondingly higher data transmission rates.

3.2 Radio signal coverage

Compared to analog PMR systems operating at 160 MHz, the coverage of a TETRA system is smaller. This is due to the higher RF carrier frequency (400 MHz) and limited transmission power (average transmission power is up to 2,5 W for mobile stations and up to 0,25 W for handheld stations).

Since coverage can only be measured after installing RF equipment, computer simulation is usually employed to estimate it in order to find or confirm the necessary number of base stations and their placement for an adequate coverage. A large number of propagation models has been created, many of which are limited to certain environments and carrier frequency bands. The models can be divided into three groups, empirical, deterministic, and an intermediate semi-deterministic group [14]. The deterministic models are based on the physical properties of radio propagation and can produce very accurate results if given precise and exhaustive data about the environment. However, preparing this data for a large-scale environment is not an easy task, and the algorithms are very computing-demanding. For this reasons the empirical or semi-deterministic models are usually chosen for large geographical areas like cities and countries.

Estimation of TETRA coverage for Elektro Ljubljana has been performed using the well established Longley-Rice model [15]. The estimated coverage for Elektro Ljubljana from the 8 existing (analog) base station locations is shown in Figure 4.

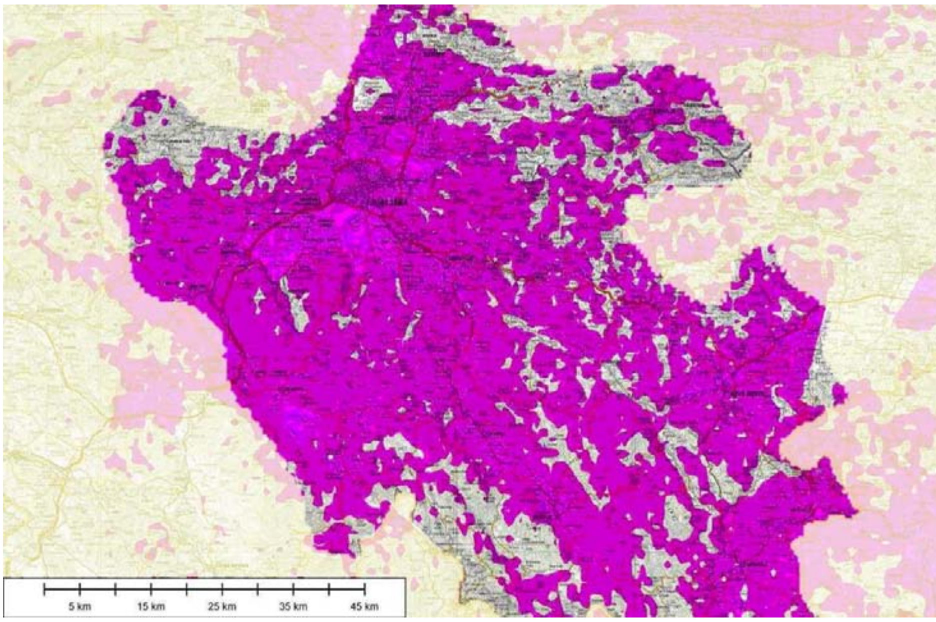

Fig. 4: TETRA radio signal coverage from existing locations

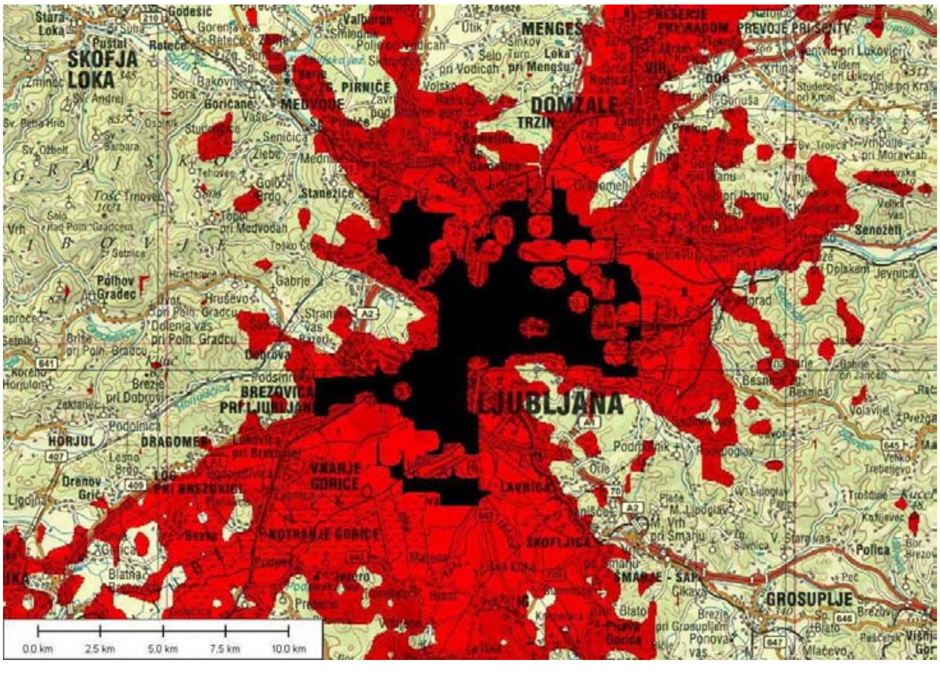

Fig. 5: Coverage from a building in Ljubljana, TETRA (gray) and WiMAX (black)

Better coverage would require a larger number of base station locations compared to the existing 160 MHz analog PMR radio network.

We have also considered a possibility to use the new broadband wireless access system WiMAX as the communication infrastructure. Since this is basically a data communication network, voice communication would be realized with VoIP (Voice-over-IP protocol). WiMAX uses a much higher RF band, usually at 3,5 GHz, which results in a smaller coverage compared to TETRA. The situation is clearly illustrated in Figure 5, which shows simulation results for a single base station in the city of Ljubljana [16]. The outer gray shape represents the TETRA coverage and the inner black one the WiMAX coverage. This renders WiMAX unsuitable for this task unless a very dense network of base stations is built on the whole territory.

4 Data applications in electric power distribution

Besides standard voice applications (communication between the dispatchers and workers in the field), TETRA also provides data communication that can be used for telemetry and telecontrol. Telemetry is a process by which automatic measurements and/or other data are collected and processed at a remote site and transmitted to a receiving station for monitoring, analysis and recording. Telecontrol is a process of controlling the operation of remote devices from a control station. A typical telemetry or telecontrol system [17] includes three basic procedures:

- Remote site data acquisition and output device control.
- Data transmission between the control centre and remote units.
- Control centre data analysis and remote device control.

Various telemetry and telecontrol applications exist in an electric power distribution system that could make use of the TETRA communication network. They encompass:

- Remote control and supervision of circuit breakers and disconnectors.
- Remote control and supervision of power plants.
- Remote electricity meter reading.

Each TETRA base station should use at least two RF carriers to achieve adequate reliability in case of breakdown of a single RF transmitter and related equipment. Thus, seven communication channels would be available for users (one is reserved for the TETRA system use), which can be freely shared between voice and data communication.

In the sequel, the above mentioned applications are analyzed in greater detail.

4.1 Remote control and supervision of circuit breakers and disconnectors

A medium voltage power distribution network incorporates a large number of remote circuit breakers and disconnectors distributed over the whole network territory and located on power line poles. In a broader sense this problem is similar to the remote control of power plants, however it deserves special treatment because of its special properties:

- It consists of a great number of control points distributed over the whole territory served by a particular electric distribution company.
- As a rule, and in contrast to large power plants, there are no available communication lines (wired or optical) to these points.
- The required functionality of each control point is relatively simple, requiring simple processing and communication equipment with only periodical communication and low data throughput, for which TETRA is a very suitable solution.

In the distribution network of Elektro Ljubljana there are currently around 80 automated (remote controlled) circuit breaker/disconnector points. Their locations are shown in Figures 6 and 7. Automation of up to 200 remote circuit breaker/disconnector points is expected in the future.

Currently, the public GSM mobile phone system is used for remote control and supervision, which constitutes a considerable problem regarding operational reliability. Especially in emergency situations, when remote control would be especially important, there is a high probability that the GSM network would be overloaded by public voice calls.

In the current system, data links are established only when data have to be transferred. The connection setup process in GSM is quite lengthy compared to that in TETRA and cannot be neglected, especially compared to the time needed for the small amount of data to be transferred, and causes delays in control and supervision.

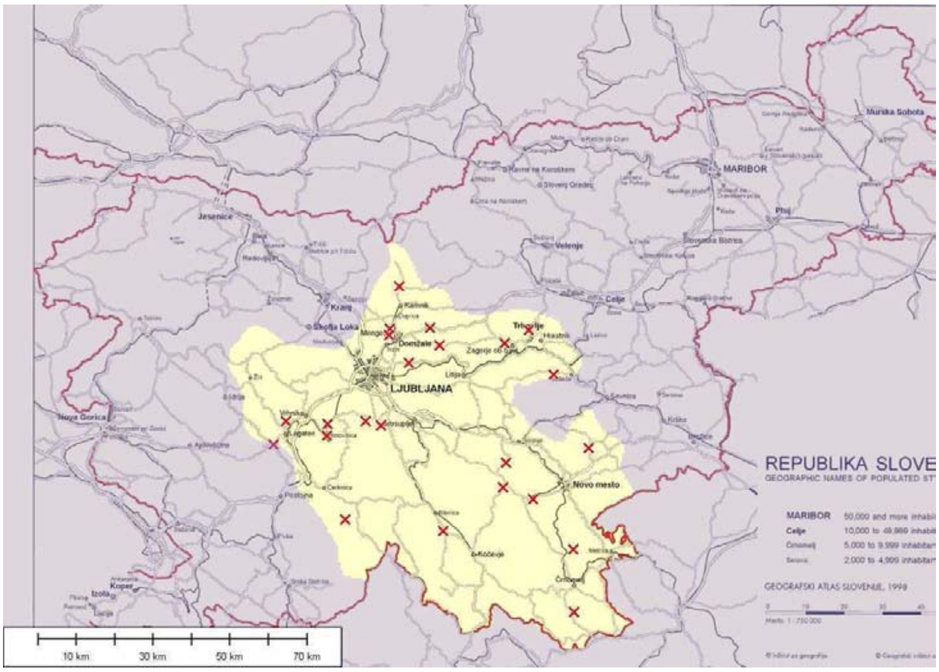

Fig. 6: Circuit breaker locations (Elektro Ljubljana)

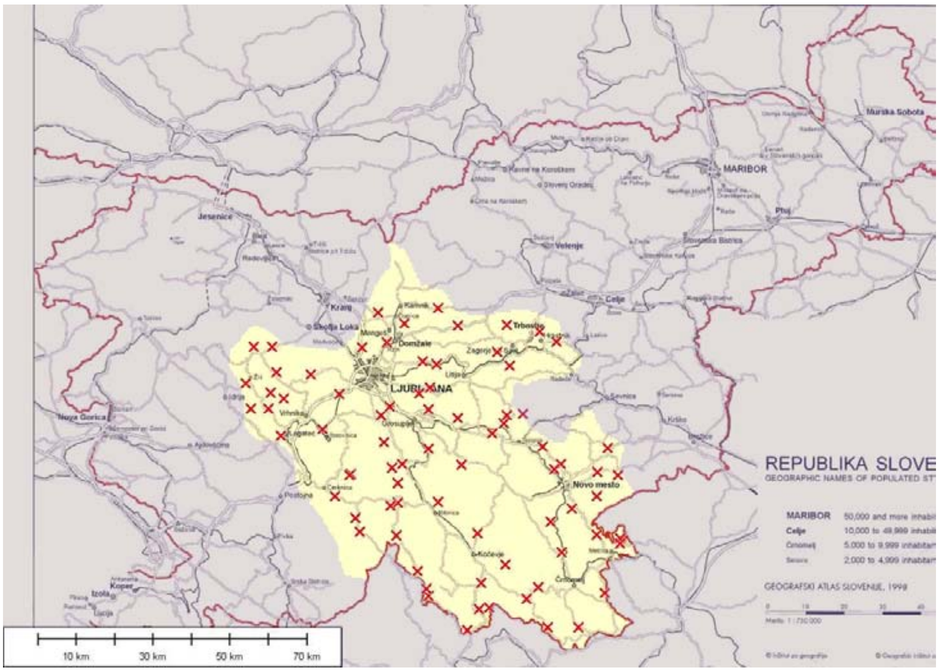

Fig. 7: Circuit disconnector locations (Elektro Ljubljana)

4.1.1 Traffic analysis

Currently there are around 80 breakers and disconnectors in operation. In the future, their number is planned to be increased to 200. In normal operation of the power network, breakers/ disconnectors are in fixed positions and no communication is required except for checking their operational status, which is performed four times a day. In addition to this, there are up to 40 remote manipulations per breaker/disconnector yearly due to power network problems and breakdowns. The call duration for each remote access has been estimated to be about one minute. This time includes establishing the GSM call, which can require a considerable time. With the TETRA's fast call setup time of 0,3 s, using the highest protection of data transfer with the speed of 2400 bit/s, and estimating the communication and protocol overhead to be about 50% of the specified data rate (giving 1200 bit/s effective data transmission rate), around 7 kB of user data could be transferred in one minute, which should in any case suffice for the remote control of breakers/disconnectors.

Table 4 summarizes the maximum estimated number of calls and cumulative call duration for the remote breaker/connection control.

Table 4: Number of calls and call duration

	No. of calls (1min/call)	Cumulative call time (200 break./discon.)
Idle	4 / day	800 min/day
Interventions	40 / year	8000 min/year

Lacking accurate and detailed data and statistics about the emergency switch operations over the past years we assumed the following worst case scenario:

- All intervening calls are made on one single worst day of the year, spanned evenly across the 24 hour period.
- All the calls are evenly distributed between 20 base stations (estimated as the smallest number of base stations for adequate coverage of the Elektro Ljubljana geographic area).

The cumulative time required for these calls, for each base station (using a single data channel), is then:

$$T_{BS} = \frac{T_{CALL} N_{BD} N_{BDCALLS}}{N_{BS}} \quad (1)$$

T_{BS} - cumulative call duration for each base station
T_{CALL} - average call duration
N_{BD} - number of breakers/disconnectors
$N_{BDCALLS}$ - number of calls per breaker/disconnectors on the worst day of the year
N_{BS} - number of base stations

With an average data call duration of 1 minute, 200 remotely controlled breakers/disconnectors with 44 calls for each one on the worst day of the year, and 20 base stations, the cumulative time of all data communication calls on a single base station would be:

$$T_{BS} = \frac{1\min \times 200 \times 44}{20} = 440\min \quad (2)$$

This represents the following average loading of a single base station communication channel:

$$L_{BS} = \frac{T_{BS}}{T_{DAY}} = \frac{440\min}{24 \times 60\min} = 30{,}56\% \quad (3)$$

4.1.2 TETRA suitability

We can thus conclude that a single data channel on each TETRA base station would be sufficient for remote control of breaker and disconnectors. The amount of transferred data in normal situations is low with only two to four calls daily. Even in emergency situations one data channel per base station would be sufficient for this application.

TETRA would be a good solution for this application. However, good radio signal coverage would be required, which means building an adequate number of base stations. Individual breaker/disconnector locations or smaller areas without direct base station coverage could be reached via intermediate TETRA terminals working as repeaters. Figure 8 shows the locations of existing automated breakers/disconnector and distribution substations, together with the estimated radio coverage from 13 TETRA base stations.

4.2 Remote control and supervision of power plants

An electric power distribution network consists of a large number of substations with electric power switch devices and transformers. They are mostly located close to bigger cities or large electric power consumers (industry) where fixed communication links are normally available for remote control and supervision. Here, TETRA could be used as a secondary (backup) system for emergency cases when the main wired communication network is damaged. In backup mode, the remote control and supervision system should be able to operate with the limited TETRA data transmission speed (a few kb/s, see Table 2), which is substantially lower than that of optical or wired-line communication links.

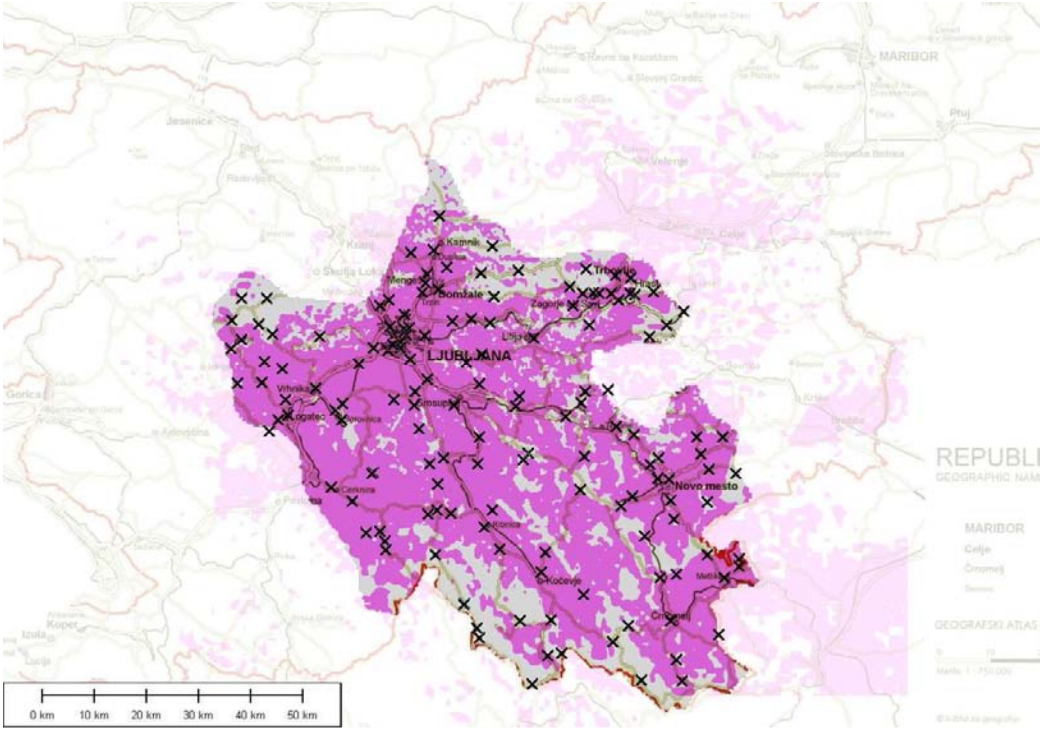

Fig. 8: Locations of power plants (automated breakers/disconnectors and distribution substations) and TETRA signal coverage

4.3 Remote electricity meter reading

An important data application in electric energy distribution is remote electricity meter reading. The consumers can be divided into two groups:

- Large consumers (industrial/commercial). This is a relatively small group, but with a large power consumption. Elektro Ljubljana has currently around 3000 large consumers. Daily meter reading is required, each producing about 16,5 kB of data. Remote reading is already implemented and, in more than half the cases (2000), it is done by wireless communication using the public GSM system.
- Household consumers. Only monthly reading is required, which is currently done manually, although there are some experiments with remote reading going on. The amount of data per reading is estimated to be about the same as for the commercial customers.

The implemented remote reading system based on the use of GSM is not without problems, nevertheless this is a suitable solution since the process is not time-critical and GSM provides good radio coverage of the whole territory.

The use of TETRA has been considered for remote metering of electricity consumption. By this, technical problems and expenses related to GSM would be avoided, assuming that no additional investment in TETRA is required.

4.3.1 Traffic analysis

The time required to transfer electricity measurement data over a TETRA network, with communication traffic evenly distributed across a certain number of base stations and using a single data channel per base station, can be expressed as:

$$T = \frac{D\,N_C}{R\,N_{BS}} \tag{4}$$

T - Communication time per base station (single communication channel) for all customers (household / commercial) & one measurement

D - amount of data per measurement

R - net TETRA data rate

N_C - number of customers

N_{BS} - number of base stations

For 300.000 household customers, 16,5 kB for each data measurement and the net TETRA data rate of 1200 bit/s (150 B/s), the *monthly* usage of a single communication channel on each base station is:

$$T_{H,monthly} = \frac{16{,}5\,\mathrm{kB} \times 300.000}{150\,\mathrm{B/s} \times 20} = 1.689.600\,\mathrm{s} \quad (5)$$

which represent the following average loading of the channel on each base station:

$$\frac{T_{H,monthly}}{1\mathrm{month}} = \frac{1.689.600}{30 \times 24 \times 60 \times 60} = 65{,}185\% \quad (6)$$

Likewise, for 3000 commercial customers, the *daily* usage of a single communication channel on each base station is:

$$T_{C,daily} = \frac{16{,}5\,\mathrm{kB} \times 3.000}{150\,\mathrm{B/s} \times 20} = 16.896\,\mathrm{s} \quad (7)$$

which involves the following average loading of the channel:

$$\frac{T_{C,daily}}{1\mathrm{day}} = \frac{16.896}{24 \times 60 \times 60} = 19{,}556\% \quad (8)$$

Hence, the total loading for both groups of customers is 84,74%.

4.3.2 TETRA suitability

The above analysis has shown that remote electricity meter reading could be served by a single TETRA communication channel. Since the operation is not time critical it could share the same data channel with the remote control and supervision of circuit breakers and disconnectors. In normal circumstances this latter data traffic is low and both applications would not disturb each other, while in emergency situations the remote metering, as a non-critical lower-priority operation, would use the remaining data channel capacity, possibly resulting in some delay in the transmission of the measured data.

However, the use of TETRA for this purpose involves certain difficulties. The main one is the large number of household customers which, with the current prices of terminals, would make it expensive. Supporting such a large number of terminals by a TETRA switch would also be expensive and could even be technically questionable, depending on the particular manufacturer and product, since TETRA systems are generally developed to be used as PMR systems for voice communication with a smaller number of terminals.

An additional problem would be the non-uniform distribution of consumers, who are concentrated in urban areas, which would require additional investment in infrastructure in those areas.

The conclusion is that the TETRA system is not appropriate for a massive remote metering application due to the large number of terminals required. For household consumers it would be sensible to collect measurements at the transformer stations (around 4.000 of them on the territory served by Elektro Ljubljana) using other dedicated shorter range communication systems (wireless, power-line). From there on, the measurements could be transferred over existing wired communication links, while TETRA would be used only in places where no other communication option were available.

The range of possible data application suitable for TETRA are currently somewhat limited by the available low bit rate. The next generation will change this considerably by introducing TEDS. Another possibility is related to WiMAX in case an already proposed lower 700 MHz frequency band is reserved for its use, which would improve its range and coverage [18]. These developments will be considered in our future work.

5 Conclusion

We investigated the possible use of the TETRA communication system for data transmission in electric power distribution systems, using the Elektro Ljubljana distribution company as an example.

TETRA is a modern digital PMR system. As the existing analog PMR systems are slowly becoming obsolete and analog technology is everywhere being replaced by digital, we can expect that the need to replace analog PMR with TETRA will grow in the near future. The necessary equipment is more expensive, but it also provides greater functionality for voice and data communications, including support for the standard IP protocol.

In the framework of an electric power distribution system, data communications can be used for various purposes like remote control of circuit breakers and disconnectors, control and supervision of power plants, and remote electric meter reading. Because of its limited capacity for communication channels TETRA is suitable for use mostly in cases where other communication channels are not available.

It must be kept in mind that TETRA, due to its technical characteristics (higher RF carrier frequency, limited transmission power), requires a larger number of base stations compared to analog VHF PMR systems. Because of that and of the equipment complexity, investment in infrastructure is higher. The expenses can be much reduced if a number of users (organisations, companies) decide to build a common system since TETRA supports virtual networks and hence independent sharing of its communication infrastructure.

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