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LTE Relocation towards Broadband PPDR System in TETRA Network

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Abstract: Transitioning a Terrestrial Trunked Radio (TETRA) network to a Long-Term Evolution (LTE) network in Public Protection and Disaster Relief (PPDR) schemes is a route to the provision of future facilities requiring elevated radio interface throughput and enabling broadband PPDR (BB-PPDR) radio. TETRA network users are presently considering how a BB-PPDR network will be deployed in the years ahead. This research provides several factors of radio planning for such networks in TETRA to LTE relocation. The conclusions are drawn from the performance in which both measurements and simulations of radio-electric coverage were conducted for the real scenario for both TETRA and LTE systems in the Murcia region, Spain. The considerations proposed can help PPDR agencies estimate the cost of converting a TETRA network to an LTE network efficiently. In this research alone, the complete area is split into geographic fields of concern identified as administrative divisions (regions, municipal regions, etc.). The analysis was conducted using a radio planning tool based on a geographic information system and measurements were used to adjust the propagation models. The number of sites needed in the LTE network — for a specific quality of service (90 percent for the entire region and 85 percent for municipal areas) — is higher than for the TETRA network, according to the real scenario considered.

Keywords: Radio planning; TETRA; LTE; Radio electric; Geographical Information Systems (GIS); PPDR

1. INTRODUCTION

The conversion of a Terrestrial Trunked Radio (TETRA) network into a Long Term Evolution (LTE) network in Public Protection and Disaster Relief (PPDR) systems is a feasible solution for providing future services needing elevated radio interface throughput and enabling PPDR (BB-PPDR) broadband radio communications [1]. In Report 218, a roadmap for the shift to broadband communication in PPDR schemes was suggested by the Electronic Communication Committee (ECC) until 2025[2]. This roadmap provides for several years of coexistence of TETRA and LTE networks until the LTE scheme has all the functionalities of the PPDR schemes. The implementation of LTE for PPDR should therefore complement current TETRA networks, not replace them, which will remain the best choice for short-term mission-critical voice service.

Furthermore, users of PPDR cannot leave their present TETRA systems until a new mobile broadband network is constructed which is capable of providing radioelectric coverage equivalent to or higher than that presently offered by TETRA systems. Therefore, the LTE network should fulfill all radioelectric coverage demands presently met by the existing network before any broadband solution can replace the existing TETRA systems.

It is expected that the most plausible future scenarios for delivering the increasingly data-intensive applications required by PPDR agencies will be based on the use of dedicated and commercial LTE networks [3]. For rural regions, a radio communication system's base stations are situated in the hills, and radio coverage has' dark zones' (without radio coverage), generally in trees, hills, rivers, etc. Operators do not want to deploy fresh base stations in these areas to provide broadband communications. However, operators have already implemented commercial broadband networks in urban settings, which could be used for broadband communications by PPDR agencies. Thus, an interesting alternative for BB-PPDR radio communications could be the possibility of a hybrid model (dedicated network for rural regions and business networks for urban areas).

According to The Critical Communications Association (TCCA), over 114 nations around the globe have implemented TETRA networks (at regional or national level) in recent years [4]. Now, these network consumers are considering how to continue in the coming years with achieving a BB-PPDR network. PPDR agencies are

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therefore interested in analyzing the many issues involved in planning the transition from a TETRA network to an LTE network (cost analysis of the required resources, expected radio coverage, quality of service, etc.).

Rouil et al.[5] presented a framework for modeling and planning a LTE broadband public safety network. The research was conducted nationwide, splitting the complete region into 20 x 20 km squares and establishing a minimum percentage of radioelectric coverage in each square.

In this research, several factors of radio planning are provided for PPDR networks in the TETRA to LTE relocation. In this situation, the complete area, distinct from the job of Rouil et al.[5], is split into geographical fields of concern identified as administrative divisions (regions, municipal regions, natural parks, etc.). To illustrate this proposal, in a rural area with an existing TETRA network that has to transition to an LTE system, a radioelectric coverage analysis was carried out in a real scenario using simulations and measurements. The analysis was conducted by exploiting the potential of a radio planning tool[6] based on a geographic information system (GIS)[7], and the measurements were conducted and used to tuning propagation models. The methodology suggested can assist PPDR organizations to assess the cost of transferring a TETRA network to an LTE network effectively.

2. RADIO PLANNING ASPECTS

2.1 Scenario

RADIECARM is the TETRA network used by the Regional Government of Murcia (Spain) for emergency and security services (fire brigade, police, forest police, etc.). The 112 Emergency Coordination Center coordinates all of these services. RADIECARM is a devoted network of 16 mountain base stations and about 2000 terminals. Figure 1 shows the typical facilities (tower, machinery, etc.) at a site and a portable terminal mounted on a four-wheel drive vehicle in Figure 2. The 16 TETRA base stations (red circles) are shown in Figure 3.

Figure 1.(a) Telecommunication tower with antennas and stand

Figure 1. (b)TETRA base station equipment

Figure 2.(a) Four-wheel drive vehicle with the TETRA antenna

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Figure 2.(b) TETRA Mobile station equipment

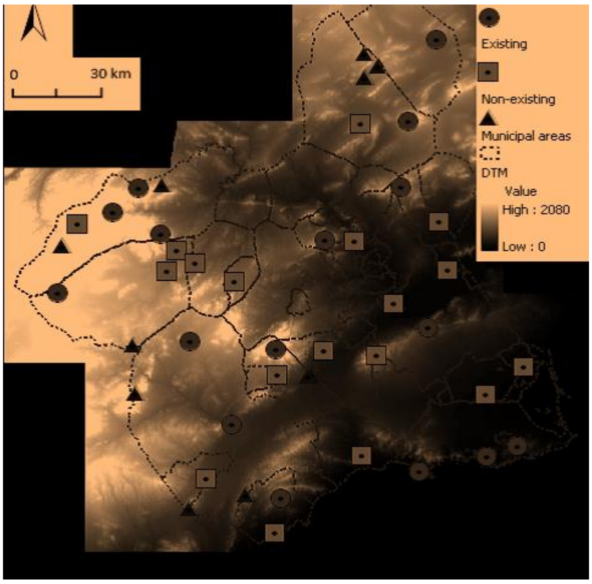

Figure 3. Digital terrain model (raster), sites (vector points) and municipal areas (vector polygons).

2.2 Radio Planning Tool

The RADIOGIS application [6], a tool developed by the authors to manage and calculate the radioelectric coverage of radio communication systems such as GSM, UMTS, LTE, TETRA, TDT, WiFi, etc., was used to perform the radioelectric coverage analysis. RADIOGIS operates on Windows PCs and is integrated into ESRI's ArcGIS 9.1 GIS software. Among other functionalities, RADIOGIS has the following:

- ➢ Calculations of radioelectric power, electric field or power density coverage while selecting the propagation model to be used: ITUR-526 [8] and ITUR-1546 [9] for rural environments; Okumura-Hata [10], COST-231 [11] and Walfisch-Bertoni [12] for urban environments.
- ➢ Calculations of the percentage limit using a vector layer with municipal regions, roads, etc.
- ➢ Site database management, radioelectric coverage of power density, power systems, measuring campaigns, etc.

2.3 Frequency Bands

The frequency range for RADIECARM is 380–385 MHz (uplink, UL) and 390–395 (downlink, DL) for the existing TETRA network, which is the band reserved for European PPDR systems [13].

Several possibilities are available for the new LTE network for the frequency band. ECC Report 218[2] develops the conditions necessary for the creation of a harmonized European framework for future BB-PPDR systems implementation. This report proposes the 'flexible harmonization' concept to enable BB-PPDR systems to be implemented effectively. The bands of frequencies identified as harmonization candidates are:

- ❖ 400 MHz (410–430 MHz and 450–470 MHz)
- ❖ 700 MHz (694–790 MHz)

The frequency bands 699–716 MHz (UL) and 729–746 MHz (DL) have been used in our assessment. These frequency bands comply with the spectrum laws set out in Spain's National Table of Frequency Allocations for public safety users and broadband services. Moreover, according to the ETSI, they are E-UTRA operating bands [14, 15].

2.4 Digital Information

The region of Murcia (South-West Spain) is 11,296 km^2. The territory is divided into 45 municipalities and one zone (municipal area) is defined by each municipality (see Figure 3). Geographical data was acquired from Spain's National Geographical Institute. A Digital Terrain Model (DTM)—in a raster format [7]—with a cell size of 100 x 100 m (see Figure 3)—was used for calculations of radioelectric coverage in rural settings, representing a compromise between precision and computing time. The municipal areas can also be observed as a vector layer with an associated attribute table containing information (name, extension, population, etc.) in Figure 3[7].

2.5 Quality of Service (QoS)

The received signal in mobile communication presents broad random variations that can be modeled through the introduction of a statistical correction. A fade margin

(FM) is defined by this statistical correction. If the FM is equal to zero, only 50 percent of the locations in the cell (defined in the DTM) are guaranteed for radioelectric coverage. The percentage of locations in the cell where radioelectric coverage is guaranteed is defined as the micro scalar quality. This quality sets the fade margin regarded in the budget for the connection.

The FM can be estimated by assuming a log-normal distribution by:

$$FM\,(\text{dB}) = K(\text{L}) \cdot \sigma_{\text{L}} \tag{1}$$

Where σ_{L}(dB) is the cell location variation and case K(L) is the standardized location abscissa (L) allocation percentage. The K parameter is connected by the expression to the inverse function of Gauss G^{-1}(L):

$$K(\text{L}) = \text{G}^{-1}\,(1 - \text{L}/100) \tag{2}$$

A shadowing standard deviation with locations at 6 dB is a typical value for the UHF band in rural environments for calculations. If we set a 90% micro scalar quality, the fade margin is:

$$FM\,(\text{dB}) = 1.28\ 6 = 7.7\ \text{dB} \tag{3}$$

The proportion of cells with radioelectric coverage in a region is the macro scalar quality. A polygon, which in our case constitutes a municipal or regional region, could delimit this region. We presumed a macro-scalar value of 90% for the regional term and 85% for the municipal term in our calculations.

2.6 Propagation Model

Many propagation models, such as the Longley – Rice [16], Bullington [17], Vogler [18], Luebbers [19] and Deygout [20] models, have been used in rural UHF band planning in relation to the guidelines of the International Telecommunications Union (ITU-R) Radio Sector [8,9]. All of these models estimate the mean value of the received signal in each DTM cell, taking the terrain profile between the transmitter and the receiver into consideration.

The propagation loss is evaluated for each terrain profile in the radio planning tool used by:

$$L\,(\text{dB}) = L_0 + L_{\text{Terrain irregularities}} + L_{\text{Close environment}} \tag{4}$$

where L_O is the free space loss, that can be calculated by:

$$L_0\,(\text{dB}) = 33.44 + 20\log f\,(\text{MHz}) + 20\log d\,(\text{km}) \tag{5}$$

$L_{\text{Terrain irregularities}}$ are the loss of diffraction resulting from terrain obstruction. This propagation loss can be estimated for rural environments using recommendation ITU-R P.526 [8]. $L_{\text{Close environment}}$ is the loss of propagation, taking into account the phenomenon of multipaths. This loss is directly linked to the mobile's surrounding morphography. A raster with a resolution of 100x 100 m was developed in the GIS, with each cell having a value (in dB) representing the loss owing to the sort of setting (rural pine forests, suburban environment and metropolitan environment). To evaluate the value for suburban and urban environments, the Hata model [10] was used. The authors carried out a measurement campaign for the TETRA system (400 MHz) consisting of five routes within a prototype— including three base stations— to estimate the path loss for the rural (pine forest) environment. The values acquired for the TETRA scheme are shown in Table 1. In addition, the values for the LTE scheme (700 MHz) are also provided in this table, in which the rural environment losses were estimated by considering ITU-R P.833 [21]. These values were introduced to this study's simulations. Figure 4 indicates a comparison in one of the paths between the propagation model and the measurements. Table 2 shows the mean error and standard deviation of the differences for each route between the propagation model and the measurements.

Table 1. Obtained path loss for the different types of environments considered

Type of Environment	**$L_{\text{Close environment}}$ (dB) (400 MHz, TETRA)**	**$L_{\text{Close environment}}$ (dB) (700 MHz, LTE)**
No value	**0**	**0**
Rural (pine forest)	**10**	**14.5**
Suburban	**13.75**	**13.76**
Urban	**25.65**	**27.52**

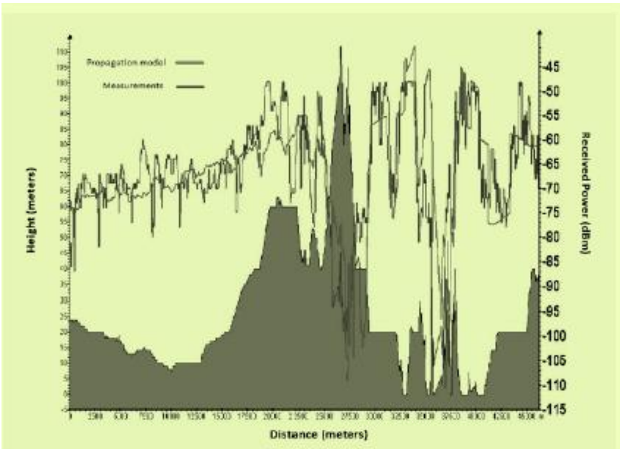

Figure 4. Comparison between measurements and propagations model

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Table 2. Mean error and standard deviation of the difference between the propagation model and measurements for each route

Route Number	Mean Error (dB)	Standard Deviation (dB)
I	1.04	8.34
II	8.96	9.20
III	3.63	8.45
IV	-0.44	7.58
V	10.65	12.19

2.7 Link Budget

Table 3 presents the link budget for TETRA and LTE and downlink (DL) and uplink (UL) systems. For a mobile receiver, the link budget was calculated in which the antennas are mounted on a vehicle with a gain of 2 dBi for the TETRA system and 3.5 dBi for the LTE system. The antennas also have an omnidirectional model for the TETRA system with a gain of 7 dBi and a directional pattern with a gain of 15 dBi for the LTE system in the base station.

Table 3. Link budget for the TETRA and LTE systems

			TETRA		LTE	
Parameter	Units		DL	UL	DL	UL
Power Tx	dBm	P_{tx}	44	40	35	28
Gain Tx	dBi	G_{tx}	7	2	15	3.5
Losses Tx	dB	L_{tx}	2	0.5	2	0.5
PIRE	dBm	$P_{tx} + G_{tx} - L_{tx}$	50	41.5	48	31
Fade Margin	dB	FM (90%)	7.7	7.7	7.7	7.7
Gain Rx	dBi	G_{rx}	2	7	3.5	15
Losses Rx	dB	L_{rx}	0.5	2	0.5	2
Bandwidth		BW	25 kHz		5 MHz	
Sensitivity	dBm	S	−103	−106	−95	−100
Lmax	dB	$PIRE - FM + G_{rx} - L_{rx} - S$	146.3	144.8	138.3	136.3

For a rural environment, radio-electric coverage has been calculated, so a noise-limited scenario has been assumed. The sensitivity for the LTE system is calculated by:

$$S\,(\mathrm{dBm}) = -174 + F + 10\log(Nrb \times RB) + SNIR \quad (6)$$

Where F is the noise figure (7 dB for DL and 2 dB for UL), Nrb is the number of resource blocks (25 for radio channel bandwidth of 5 MHz), RB is the bandwidth of each resource block (180 kHz) and SNIR is the mean signal-to-interference-and-noise ratio (5 dB).

A real 4.5 Mbps throughput can be achieved in the proposed UL for LTE with a sensitivity of -100 dBm using a 16 QAM modulation, enabling full HD (1920 X 1080) video streaming to be transmitted. The maximum path loss (L_{max}) for the TETRA system is in accordance with Dunlop et al.[22] and for the LTE system with Elnashar et al.[23]. As shown in Table 3, the worst situation for both systems is the UL, and the highest route losses that can be compensated for are 144.8 dB for the TETRA system and 136.3 dB for the LTE system.

2.8 Radioelectric Coverage Calculations

For a site, individual radioelectric coverage can be calculated using the radio planning tool, taking into account the maximum propagation loss allowed by the link budget. Then global radio coverage is calculated based on the best server principle (the highest value is the value of each cell covered by multiple locations). Using a raster and a vector point layer, each radioelectric coverage is stored in the GIS. The raster had the same resolution as the DTM and now the received energy was the value of each cell. The vector point layer also has a related attribute table that contains all the data used in the calculations: transmitter power, loss of transmission, antenna gains, frequency, propagation model, etc. This allows us to use all GIS facilities to manage and doing spatial data calculations.

It is easy to calculate the percentage of radioelectric coverage in GIS as the radioelectric coverage has been stored as a raster. GIS[7] functionality allowing operation between a raster and a vector layer can be used to evaluate the macro scalar quality of service (defined in Section 2.5, using a raster of global radioelectric coverage and municipal vector polygon layer. Also stored as a raster, the map of macro scalar quality can be represented and managed in the GIS environment.

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2.9 Methodology for Planning the New LTE Network

Figure 5 shows the proposed flow-chart to plan the new LTE network.

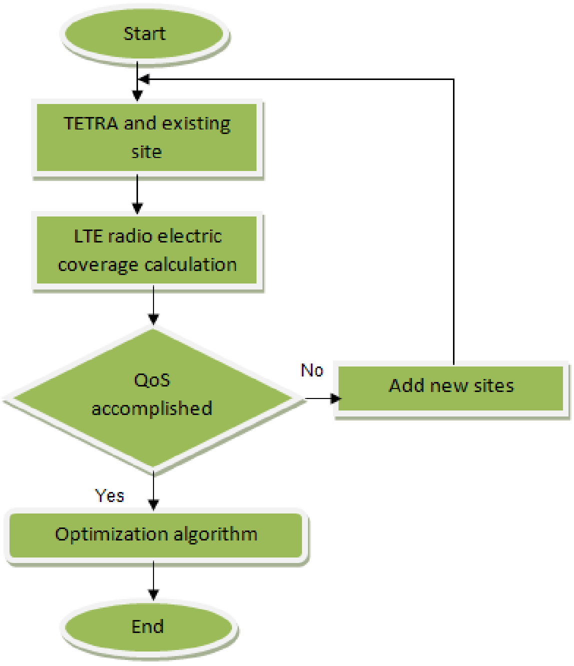

Figure 5. The proposed flow-chart to plan the new LTE network.

First, for each municipal region, the LTE radio coverage is calculated using current TETRA sites and current sites with other radio communication technologies (not TETRA). This results in a total of 34 locations (16 TETRA base stations and the 18 current sites) in our situation (Figure 3).

✓ If the QoS (see section 2.5) is fulfilled, the following optimization algorithm can be applied: Initially, individual radioelectric coverage was calculated for the available sites and ordered from the lowest to the highest radioelectric coverage in a table. Then an iterative process was carried out for each site starting with the first element (the one with the least radio coverage) and the same sequential order (from top to bottom). The following steps are implemented in each iteration:

❖ The corresponding table element is dismissed.

❖ Global radioelectric coverage is calculated with sites that are not discarded or removed.

❖ If the macro-scalar quality for the region and municipal regions is achieved, the site discarded in step 1 will be removed and, if not, the site will be retained in the table.

✓ This implies that more locations are required if the QoS is not achieved. The sites that do not yet exist but can be constructed with the required facilities (telecommunications tower, electrical line, stands, etc.). The location for which the dark zones on the global radio coverage map are estimated should be gradually added until the QoS is complete. Then it is possible to apply the earlier stated optimization algorithm.

3. RESULT AND DISCUSSION

3.1 The Existing TETRA Network

The 16 TETRA base stations are used to calculate the radioelectric coverage (Figure 6a). Table 4 shows the radio-electric coverage percentage for each municipal area. The macro scalar quality is, as can be observed, above 90 percent for the region and 85 percent for the municipal areas.

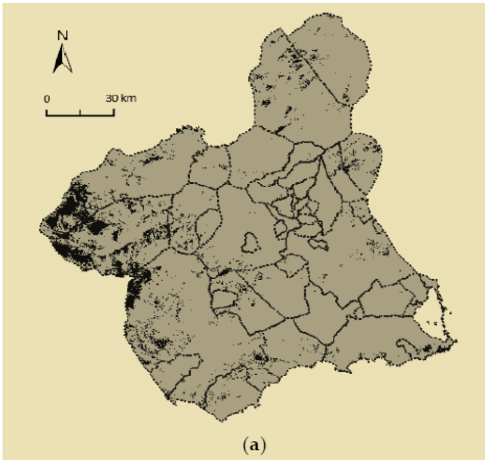

Figure 6. Radioelectric coverage for (a) the TETRA system (16 sites)

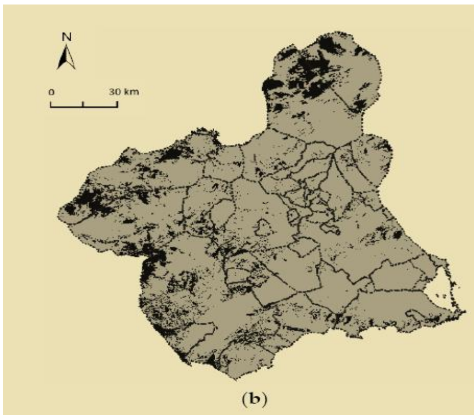

Figure 6. Radioelectric coverage for (b) the LTE system (34 sites)

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Table 4. Percentage of radioelectric coverage in municipal areas

Municipal Area	% TETRA Radioelectric Coverage (16 Sites)	% LTE Radioelectric Coverage (34 Sites)	% LTE Radioelectric Coverage (46 Sites)	% LTE Radioelectric Coverage (39 Sites) (Optimized)
Abanilla	95	87	87	87
Abarán	97	97	97	96
Águilas	89	87	87	87
Albudeite	100	94	94	94
Alcantarilla	100	100	100	100
Aledo	100	96	98	95
Alguazas	100	96	96	96
Alhama	94	97	97	96
Archena	100	95	95	95
Beniel	100	100	100	96
Blanca	99	96	96	96
Bullas	96	96	96	96
Calasparra	96	91	91	91
Campos del Rio	100	98	98	98
Caravaca	93	79	85	85
Cartagena	95	90	90	88
Cehegin	90	85	85	85
Ceuti	100	93	93	93
Cieza	98	92	92	92
Fortuna	99	93	93	93
Fuente Álamo	99	98	98	98
Jumilla	87	75	92	92
Librilla	94	99	99	99
Lorca	90	78	85	85
Lorqui	100	97	97	97
Mazarrón	94	89	89	88
Molina de Segura	100	98	98	98
Moratalla	86	71	85	85
Mula	96	91	91	91
Murcia	96	94	94	92
Ojós	98	95	95	94
Pliego	98	95	95	95
Puerto Lumbreras	91	85	94	94
Ricote	98	97	96	95
San Javier	100	99	100	98
San Pedro del Pinatar	100	100	100	90
Torre-Pacheco	98	100	100	99
Las Torres de Cotillas	100	97	97	97
Totana	92	84	88	86
Ulea	100	98	97	96
La Unión	99	92	92	92
Villanueva	100	98	98	98
Yecla	90	73	91	91
Santomera	99	94	94	91
Los Alcázares	100	100	100	99
Region	93	85	91	90

3.2 The New LTE Network

In our case study, the methodology proposed in section 2.9 has been applied. First, the radio coverage for the new LTE network was calculated, taking into account the 16 TETRA sites mentioned above, as well as the 18 existing sites (34 in total) (see Figure 6b).

It should be noted that for the LTE network the number of 'dark zones' (blue color in Figure 6) is higher than for the network TETRA. Table 4 shows the percentage of each municipal area's radio coverage. In most cases, the macro-scalar quality of 85% for the municipal area is exceeded, except for six out of 45 municipal areas (Caravaca, Jumilla, Lorca ; Moratalla, Totana and Yecla). In addition, the region's percentage of radioelectric LTE coverage is 85 percent (below the TETRA network's actual macro-scalar quality of 90%).

At this stage, fresh locations need to be added to enhance radioelectric coverage according to the Figure 5 flow chart. With the help of the GIS, twelve more sites were found in the detected ' dark zones, ' represented as blue triangles in Figure 3. These new sites would have to be built with the infrastructure needed (telecommunications tower, electrical line, stand, etc.). They have been

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selected because they are accessible by path and receiving electrical power is easy for them. The total of 46 sites were calculated for the new radio-electric coverage (Table 4). The macro-scalar quality of service is now achieved for the municipal areas and 85% and 90% respectively for the region.The next step was to use an optimization algorithm to see if with fewer sites the same service quality could be maintained.

As can be seen in Table 4, 39 sites are sufficient to achieve the QoS. These findings show that, if we want to guarantee the same macro scalar performance for both devices, the amount of locations is a factor of 2.4 greater for the LTE network than the TETRA network. Figure 7 shows the 39-site LTE radioelectric coverage where the dark zones were reduced in relation to the 34-site case (see Figure 6b).

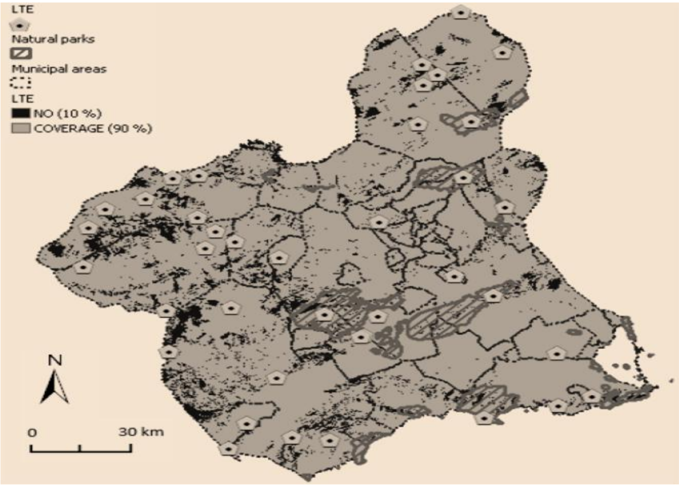

Figure 7. LTE optimized radioelectric coverage (39 sites)

Other situations of concern to PPDR organizations such as radioelectric coverage in natural parks (depicted as polygons in Figure 7) can also be analyzed. Table 5 demonstrates the proportion of each natural park's radioelectric coverage. The proportion of LTE radio coverage for 6 of 20 natural parks is less than 85 percent (assuming either 46 or 39 locations), although the proportion of radio coverage for municipal fields is equivalent to or greater than 85 percent (see Table 4). Therefore, in this case, we need to add several sites in these six natural parks to improve the radio coverage.

Table 5. Percentage of radioelectric coverage in natural parks

Natural Park	% LTE Radioelectric Coverage (46 Sites)	% LTE Radioelectric Coverage (39 Sites) (Optimized)
Enclavado	85%	85%
Sierra Salinas	97%	96%
Sierra de El Carche	88%	88%
Sierra de La Pila	90%	88%
Ribera de Cañaverosa	63%	63%
Cañón de Almadenes	53%	44%
Ajauque y Rambla Salada	99%	99%
Carrascoy y El Valle	92%	92%
Barrancos de Gebas	95%	95%
Sierra Espuña	81%	78%
Salinas y Arenales de San Pedro	100%	90%
Saladares del Guadalentín	100%	100%
Cabezo Gordo	97%	90%
Islas del Mar Menor	92%	92%
La Muela y Cabo Tiñoso	79%	79%
Calblanque	50%	40%
Sierra de las Moreras	73%	73%
Islas mediterráneo	97%	93%
Calnegre y Cabo Cope	88%	88%
Cuatro Calas	99%	98%
Total	86%	84%

4. CONCLUSIONS

In a real scenario, the conversion of an existing TETRA network operating in the 400 MHz band to a new LTE network operating in the 700 MHz band was analyzed through simulations and measurements. The latter were used to adjust the propagation models used and, in this sense, the values of the obtained path loss are offered for the different types of environments considered (morphographic correction) for both TETRA and LTE systems. Furthermore, the analysis also considered the study of special scenarios such as natural parks.

The results show that the number of sites needed in the LTE network for a specific quality of service (90 percent for the entire region and 85 percent for municipal areas) is 2.4 higher than for the TETRA network, according to the real scenario considered.

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