Synchronization in TETRA Networks

Plamen Hristov Vanchev[1], Marin Simeonov Marinov[2]

Abstract – **Digital FIR-Filter with integration on synchronization word is synthesized for communication between MSs-BSs in TETRA Networks. For solvability of the comparative level of the filter output signals and the digital integrator, the Neiman -Pierson criterion is used. In the latter according to the standards the misrouting probability (probability of false alarm) is given and the probability of successful service completion (probability of true detection) is maximized. The filter coefficients are calculated with invariant transformation of filter pulse characteristic. The sampled frequency is obtained by virtue of the criterion for receiving of maximum information from the input signal. The values of digital and analogue thresholds of the filter and the accumulator are presented for reliable synchronization making, according to the ETSI standards. Conclusions and recommendations are made for the use of the presented synchronization method in TETRA Networks.**

Keywords – **TETRA, FIR-Filter, p/4-DQPSK, Synchronization, Air Interface**

TETRA (Terrestrial Trunked Radio) is an all-digital spectrum efficient trunked LMR (Land Mobile Radio) radio system that uses a 4-slot TDMA (Time Division Multiple Access) technology. This technology provides in a 25 kHz physical radio channel 4 simultaneous logical voice and/or data paths. Alternatively, slots can be concatenated for high-speed data. The on-air data rate in the 25 kHz channels is 36 kbit/s. TETRA uses 7.2 kbit/s speech CODEC, providing clear speech quality [5-7].

I. Introducion

TETRA is defined by ETSI (the European Telecommunication Standards Institute) and is designed for PMR (Private Mobile Radio) and PAMR (Public Access Mobile Radio) utilization.

ETSI provides a suite of standards that includes Design Guides, Conformance Specifications, Air Interface Specifications and Interoperability Specifications, which describe both trunked and direct mode operations. TETRA provides voice and data communication with short data services, circuit mode and packet mode data services.

As well as ETSI a number of major TETRA users have generated specific-to-system specifications that further define the standard. TETRA is aimed at markets that range from very large regional and national public, secure and emergency service networks to on-site systems. Customers include network providers, police, fire and ambulance services, security services, gas, water and electricity utilities, mass transit authorities and operators, airports, ports and the general professional radio market.

The TETRA technology provides one-to-one or one-to-many voice and/or data communication with 'traditional' simplex PMR push-to-talk operation or duplex, cellular type, operation. Trunked mode (TMO) operation is the normal state but various managed and unmanaged direct modes (DMO) for direct communication or, via gateways, subscriber to system communication are possible. Very fast call set-up times (< 0.3 ms) are standard.

Standardization for TETRA commenced in 1990 with first phase standards completed in 1995. Harmonized frequencies across Europe were allocated by CEPT in 1996.

TETRA is now an established European standard, as well as an accepted standard in Russia, China, in many Pacific Rim and South American countries and it is within the standard acceptance procedure in the US. In particular TETRA Network will be built for Bulgarian Ministry of Defense and Bulgarian Ministry of Interior. The project will be implemented in a couple of years. This project will allow organizing 24 hours secure and reliable connection between network subscribers. The interfaces will be suitable for all types of Radio Network [7].

II. TETRA Air Interface

There are many possible variations in TETRA network topology ranging from small, on-site applications to very large, regional and national systems. In general, however, the systems have many common elements [2].

The simplest TETRA network sites consist of one or more base station transmitter/receivers, linked to a local switching center (LSC) via modems. The next most complex network site consists of one or more base station transmitter/receivers linked to the LSC directly, gateways to other systems, databases and a gateway to the rest of the TETRA network. For larger systems, a main switching center (MSC) is used where centralized network and subscriber management sub-systems are connected. Each of these basic elements is further described below.

The linking between MS to BS in TETRA is into ($380 \div 520$) MHz Frequency Band.

When used in dedicated TETRA frequency bands, TETRA MSs shall transmit in the TETRA uplink frequency band, and TETRA BSs shall transmit in the TETRA downlink frequency band. The uplink and downlink frequency bands are

[1]Plamen Hristov Vanchev, National Military University, Aviation Faculty, Department of Electronics, Communication and Navigation Equipment of the Air Craft, Dolna Mitropolia-5856, Pleven, Bulgaria, E-mails: pvanchev@af-acad.bg, pvanchev@yahoo.com

[2]Marin Simeonov Marinov, National Military University, Aviation Faculty, Department of Electronics, Communication and Navigation Equipment of the Air Craft, Dolna Mitropolia-5856, Pleven, Bulgaria, E-mails: mmarinov@af-acad.bg, mmarinov2000@yahoo.com

of equal width. Their edges shall be as follows [6]:

$$\begin{cases} F_{up,min} - F_{up,max} \text{ (MHz): } \textit{mobile transmit, base receive;} \\ F_{dw,min} - F_{dw,max} \text{ (MHz): } \textit{base transmit, mobile receive.} \end{cases} \quad (1)$$

The TETRA RF carrier separation shall be 25 kHz. The uplink and downlink bands are divided into N RF carriers. In order to ensure compliance with the radio regulations outside the band, a guard band of G kHz is needed at each side of both uplink and downlink bands.

The basic radio resource is a timeslot lasting 14,167 ms (85/6 ms) transmitting information at a modulation rate of 36 kbit/s. This means that the time slot duration, including guard and ramping times, is 510 bit (255 symbol) duration.

The following subsections briefly introduce the structures of hyper-frame, multi-frame, frame, timeslot, and burst, as well as the mapping of the logical channels onto the physical channels, shown in Fig. 1 [5].

The center frequencies of uplink RF carriers, $F_{up,c}$ shall be given by [6]:

$$F_{up,c} = F_{up,min} + 0,001G + 0,025(c - 0,5) \text{ (MHz)}, \quad \text{for} \quad c = 1, ..., N \quad (2)$$

and the corresponding center frequency of downlink RF carriers, $F_{dw,c}$, shall be given by [6]:

$$F_{dw,c} = F_{up,c} + D \quad \text{for} \quad c = 1, ..., N \quad (3)$$

When a TETRA system is operated in frequency bands used for analogue Private Mobile Radio (PMR), the uplink and downlink transmit and receive center frequencies and the duplex spacing (D) will be allocated by the National Regulatory Administration (NRA).

In all frequency bands, the TETRA stations use a fixed duplex spacing D.

The access scheme is TDMA with 4 physical channels per carrier. The carrier separation is 25 kHz.

For synchronization procedure we must know the radio interface between MS and BS (AI – Air Interface between MS and BS) for a user. The TDMA frame is separated into four

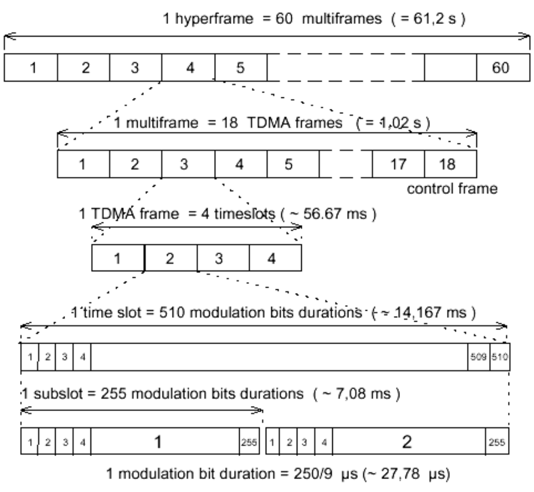

Fig. 1. TETRA TDMA structure

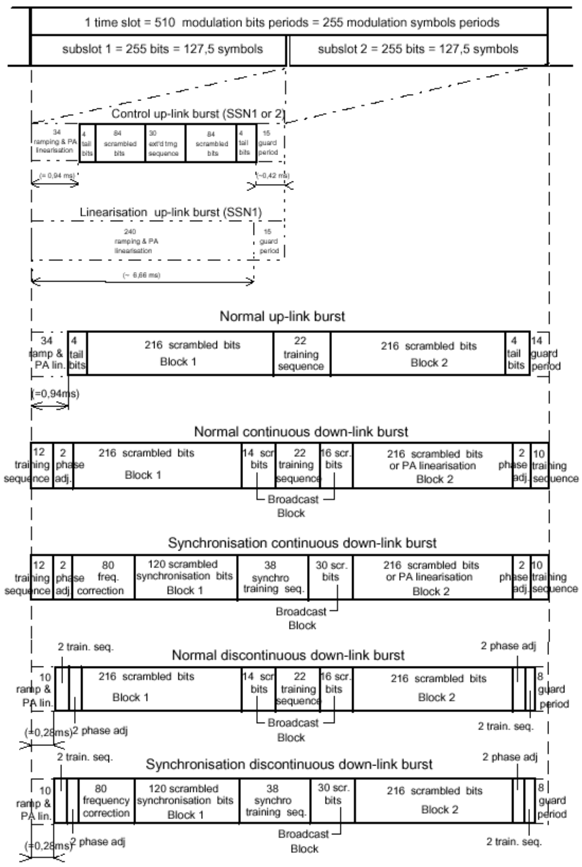

Fig. 2. Types of bursts for each TDMA Frame

time intervals, each corresponding to the client, connected with the cell (Fig. 1 and Fig. 2). The duration (type of bursts) for single TDMA frame is presented in Fig. 2 [6].

In all frequency bands, the TETRA stations use a fixed duplex spacing D.

III. TETRA Frame Synchronization Algorithm

The modulation scheme is $\pi/4$-shifted Differential Quaternary Phase Shift Keying. ($\pi/4$-DQPSK) with root-raised cosine modulation filter and a roll-off factor of 0,35 and the modulation rate is 36 kbit/s. In a $\pi/4$-QPSK transmitter, the input bit stream is partitioned by a serial-to-parallel converter into two parallel data streams $m_{I,k}$ and $m_{Q,k}$, each with a symbol rate equal to half of the incoming bit rate. The k-th in-phase (I_k) and quadrature pulses (Q_k) are produced at the output of the signal mapping circuit over time. They represent rectangular pulses over one symbol duration having amplitudes given by [8]

$$\dot{S}(t) = \begin{cases} I_k = I_{k-1} \cos\phi_k - Q_{k-1} \sin\phi_k, \\ Q_k = I_{k-1} \sin\phi_k + Q_{k-1} \cos\phi_k, \end{cases} \quad (4)$$

where the phase shift ϕ_k is related to the input symbols $m_{I,k}$ and $m_{Q,k}$, according to table 1.

The signal after demodulator can be presented with (4). This analytical expression allows using non-recursive algorithm for synchroword processing. According to the ETSI

Table 1.

Information bits $m_{I,k}$ and $m_{Q,k}$	11	01	00	10
Phase shift ϕ_k	$\pi/4$	$3\pi/4$	-$3\pi/4$	-$\pi/4$

references, multipath delays are not greater than 5 μs. It requires foreseeing the same duration into digital filter synthesis. The time interval can be taken from synchroword length, which is different, according to the information type as TSI (TETRA Subscriber Identities) and TMI (TETRA Management Identity, presented in Fig. 3 [6].

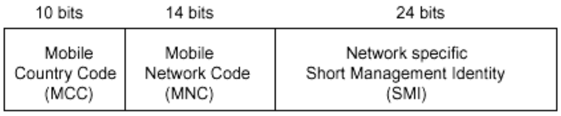

Fig. 3. Contents of TSI and TMI

To make reliable synchronization between MS and BS it is necessary to find synchroword, to process and to get a decision about its type. Synchronization signal comes in the receiver input at fixed time for every user (Fig. 2 and Fig. 3). Signal processing can be performed for whole word or for different code segments. It allows the utilization of digital filtration for synchronization procedure as data rate and modulation scheme reading.

Optimal synchrosignal finding is is possible to realize by Nayman-Pirson criterion as determination of the probability of false alarm (misrouting probability) P_F and maximization of the probability of true detection (probability of successful service completion) P_D [4]. The FIR filter syntheses can be made by invariant impulse response characteristic transformation. The filter is presented as linear time invariant (LTI) circuit and its impulse response characteristic $h(k)$ is obtained from the expected input synchronization signal as the approach for its defining is that first input sample is the final LTI circuit reaction [3]:

$$\dot{h}(k) = \dot{S}(N-1-k). \tag{5}$$

The quantized sample of input signal is made by sampled frequency $f_d = (3 \div 5)f_N$ where f_N is the Nyquist frequency. It is an implementation of the requirement about maximum amount information gain from received signal [2]. The quantized samples of synchroword can be presented as follows:

$$M = m.N. \tag{6}$$

The optimal filtration solves the convolution integral between input quantized samples and filter impulse response characteristic. When non-recursive algorithm is used output signal is obtained from the mathematical expression [1,3]:

$$\dot{y}(t) = \dot{S}(t) * \dot{h}(t). \tag{7}$$

Output complex filter signal can be calculated as follows [4]:

$$\dot{y}(t) = \sum_{n=0}^{N-1} \dot{S}(nT_i)\dot{h}(N-1-nT_i). \tag{8}$$

The decision about signal presence and signal missing is determined with the value of the output filter signal, compared with threshold h. It can be calculated with basic equations for P_F and P_D, the probabilities of false alarm and of true detection [4].

The problem of reliable synchrosignal processing can't be solved without digital integration of output FIR filter signal. After L integrations posterior misrouting probability is calculated by the expression [1,4]:

$$P_{MPO} = \sum_{k=K_0}^{L} \binom{L}{k} P_F^k (1-P_F)^{L-k}, \tag{9}$$

and posterior probability of successful service completion is defined with the equation [1,4]:

$$P_{PSSCO} = \sum_{k=K_0}^{L} \binom{L}{k} P_D^k (1-P_D)^{L-k}, \tag{10}$$

where K_0 is the minimum integration numbers after which the input probability of false alarm is obtained necessary value, according to the threshold h.

IV. Numerical Results and Simulations

Computer simulations for different SNR and different length of the synchronization sequence have been done. The results have been obtained, using 10000 realizations for each value of SNR and length of synchronization sequence. Studies have been done in the presence of noise and other $\pi/4$ QPSK modulated signals simultaneously.

Some results for estimated misrouting probabilities (MP), depending on threshold, are shown on Fig. 4 and Fig. 5. The results for typical values of SNR are represented. The solid curves illustrate the estimated MP when 8 frames are integrated. The dash curves show the estimated MP when 16 frames are integrated.

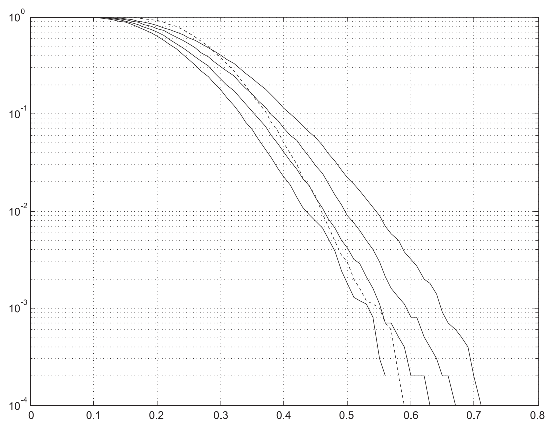

Fig. 4.

Fig. 4 shows the estimated MP for 8 bits synchroword. It's obvious that the threshold have to be determined for the lowest SNR. The determinate threshold for normalized output signal is 0.8.

Fig. 5 shows the estimated MP for 16 bits synchroword. It's obvious that the threshold have to be determined for the

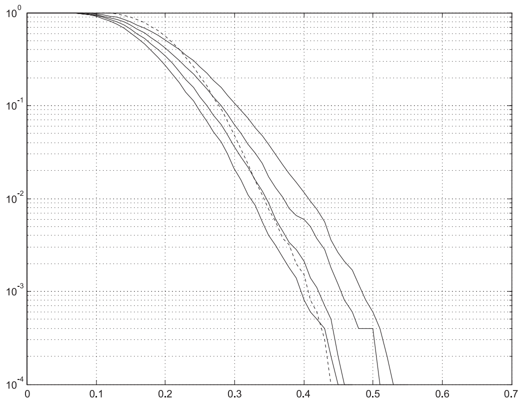

Fig. 5.

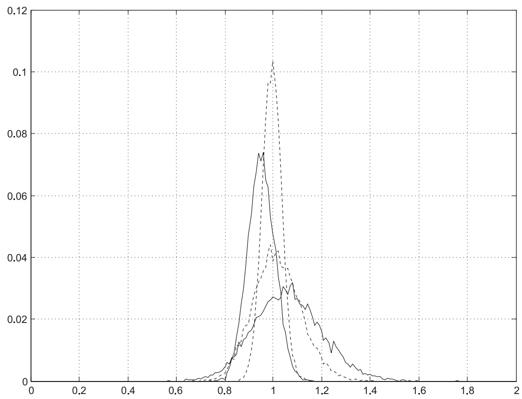

Fig. 6.

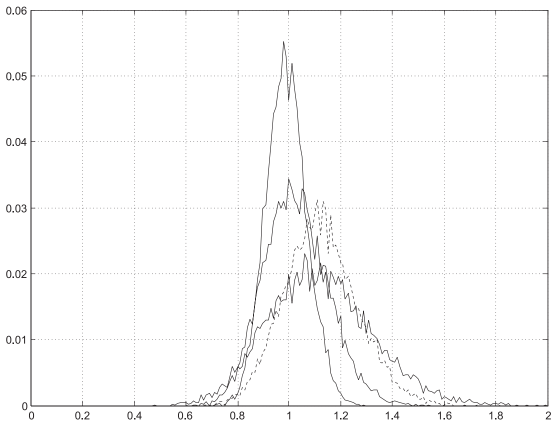

Fig. 7.

lowest SNR. The determinate threshold for normalized output signal is 0.6.

Some results of estimated probabilities of maximum output signal level (PMOSL) are shown on Fig. 6 and Fig. 7. The values of SNR are the same as on Fig. 4 and Fig. 5.

Fig. 6 shows the estimated PMOSL for 8 bits synchroword. The solid curves illustrate the estimated PMOSL when 8 frames are integrated. The dash curves illustrate the estimated PMOSL when 16 frames are integrated. Fig. 7 shows that the probability of lower maximum output signal level then threshold is negligible. The estimated probability of detection is 1 (one) for SNR > 8 dB. The cases of false alarm are 0(zero) for each set of 10000 realizations.

Fig. 8 shows that the probability of lower maximum output signal level then threshold is negligible. The estimated probability of detection is 1(one) for all SNR. The cases of false alarm are 0(zero) for each set of 10000 realizations.

Fig. 7 shows estimated PMOSL for 16 bits synchroword. These results substantiate that for secure and reliable synchronization the threshold value must exceed 0.6 or 0.8, according to the sychroword length and integration number.

V. Conclusions and Discussions

The proposed algorithm for synchronization in TETRA networks has a high reliability in the presence of noise and other $\pi/4$ QPSK modulated signals. The results of simulations shows that the performances of algorithm are very good and they meet the requirements of TETRA networks.

The core of algorithm is a digital matched filter, which can be implemented as a digital finite impulse response filter. Because the filter doesn't have to be of high order there is no need of complex software or hardware using.

References

[1] Vanchev P.H., "Frame synchronization method in VHF Frequency Hopping Spread Spectrum Radios", *Annual Reports of XXXIV Scientific Conference Communication, Electronic and Computer Systems '99*, Sofia, Bulgaria, 1999. (in Bulgarian);

[2] Marinov M.S., S.N. Ivanova, "Research of the relation to Signal to Noise Ratio on quantized frequency by transmission of PSK signals in Constricted Pass Band", *Annual Reports of XXXIII Scientific Conference Communication, Electronic and Computer Systems '98*, Sofia, Bulgaria, 1999. (in Bulgarian);

[3] Rabiner L.R., B. Gold, *Theory and Application of Digital Signal Processing*, Prentice-Hall, Inc. Englewood Cliffs, New Jersey, 1975;

[4] Tihonov V.I., V.N., Harisov, *Statistical Analysis and Synthesis of Radio engineering Equipment and Systems, Radio and Communication*, Moscow, 1991, (in Russian);

[5] ETS 300 392-1 Reference: DE/RES-06001-1 Radio Equipment and Systems (RES); Trans-European Trunked Radio (TETRA); Voice plus Data (V+D); Part 1: General network design, February 1996

[6] ETS 300 392-2 Reference: DE/RES-06001-2 Radio Equipment and Systems (RES); Trans-European Trunked Radio (TETRA); Voice plus Data (V+D); Part 2: Air Interface (AI), March 1996

[7] TETRA Overview, Securicor Wireless technology, 2001.

[8] ITU, Document 1/BL/7-E, Spectra and Bandwidth of Emissions, Annex 6, Digital Phase Modulation, 10 September 1999