OsmocomTETRA

Researching TETRA and its security

Harald Welte

gnumonks.org
gpl-violations.org
OpenBSC
OsmocomBB
hmw-consulting.de

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Outline

About the speaker

- Using + playing with Linux since 1994
- Kernel / bootloader / driver / firmware development since 1999
- IT security expert, focus on network protocol security
- Core developer of Linux packet filter netfilter/iptables
- Board-level Electrical Engineering
- Always looking for interesting protocols (RFID, DECT, GSM)

Introducing TETRA

TErrestrial Trunked RAdio

- Digital PMR (Professional Mobile Radio) standard
- Standardization Body ETSI started work in 1990
- First specified in 1995, endorsed by EU Radiocomms Committee
- Commercial Vendors: Motorola, EADS/Nokia, Arteva/Simoco/Pye/Philips, Rohde & Schwarz
- Chinese vendors are expected to appear on the market soon

TETRA vs GSM

- Longer range due to lower frequency (but not vs. GSM 410/450!)
- Higher spectral efficiency (4 speech channels in 25kHz vs. 16 speech channels in 270kHz)
- Specified to work at speeds above 400 km/h
- one-to-one, one-to-many and many-to-many (but: GSM-R ASCI)
- offers direct mode between handsets in case base station is out of range
- separate infrastructure from public networks (but: GSM-R)
- de-central fall-back, i.e. base stations switching local calls

TETRA vs GSM

Summary

- Most of the TETRA advantages could be achieved using GSM-R in a lower frequency band
- Local call switching can be implemented in GSM (think of OpenBSC)
- GSM requires modifications on the air interface for direct mode, but even in TETRA, direct mode is *very* different from trunked mode

It seems, the industry rather re-invented an entirely different system to ensure the resulting equipment can be sold at multiples of the commercial-grade GSM equipment.

TETRA deployments

- In 2009, TETRA was deployed in 114 countries (every continent except North America)
- Typical users: Police, Transportation, Army, Fire Service, Ambulance, Customs, Coast Guard
- But also: Private company networks (industrial plants)
- In Germany there are 63 registered networks (only 5 are BOS)

TETRA deployments

- Follow TETRA Newsletter released by TETRA MoU organization
- Majority of recent deployments seems to be in Asia, specifically China.
- Examples typically include police, public transportation, airports, harbours, industrial plants

TETRA Frequencies

- European Emergency Services
  - 380-383 MHz and 390-393 MHz
  - 383-385 MHz and 393-395 MHz (optional)
- European Private/Commercial Systems
  - 410-430 MHz
  - 450-470 MHz
- Other Countries
  - Depending on local regulatory requirements

TETRA Frequency plan

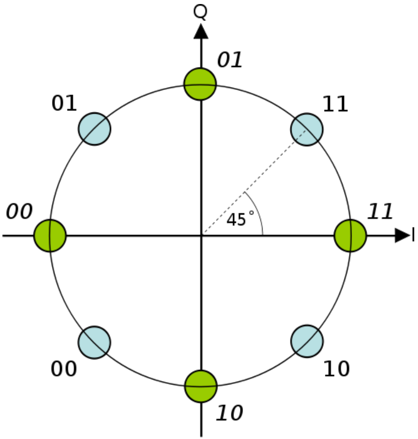
- Single TETRA carrier normally 25kHz wide, no guard bands
- Channel grid can align on 6.25, 12.5 and 25kHz offset
- This allows seamless migration / co-existence with analog FM PMR in same band
- Uplink/Downlink spacing can depend on band, typically 10MHz
- Advanced TETRA-2 modes can operate at 50, 75 or 100kHz bandwidth

TETRA Modulation

- pi/4 DQPSK (Differential Quaternary Phase Shift Keying)
- 2 bits per symbol
- Phase *difference* encodes information
- 8 phase constellations, 4 possible transitions
- Requires very linear amplifier as it is not constant envelope
- Used within TETRA at 36 kbits/sec (18 kSymbols/sec)

TETRA Modulation

pi/4 DQPSK (8 constellations, 4 transitions)



Source: Wikipedia / User:Splash

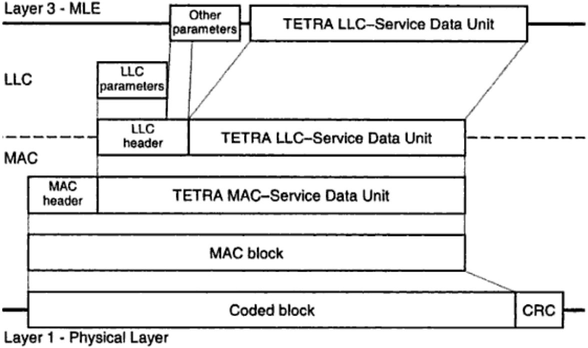
TETRA TDMA Frame structure

- Each time-slot contains 510 bits (GSM: 156)
- TDMA frame with 4 time-slots (GSM: 8)
- Duration of TDMA frame: 56.67 ms (GSM: 4.6 ms)
- Multiframe: 18 TDMA frames (GSM: 26/51)
- Hyperframe: 60 Multiframes (GSM: 2715648)

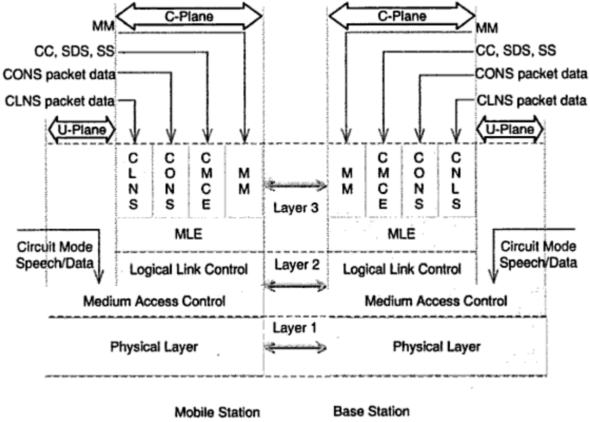
TETRA Protocol Stack

- The TETRA protocol stack is more complex than GSM
- Shared Stacking: PHY/lowerMAC/upperMAC/LLC
- Above LLC there is MLE (resembles GSM RR), on top:
  - MM (Mobility Management)
  - CMCE (Circuit Mode Control Entity)
  - CONS (Connection Oriented Service)
  - CNLS (Connectionless Service)
- Call Control, Supplementary services on top of CMCE
- Packet data on top of CNLS and CONS

TETRA Protocol Stack



TETRA Protocol Stack



CC: Call Control
CLNS: Connectionless service
CONS: Connection-oriented service
CMCE: Circuit Mode Control Entity
MLE: Mobile/Base Link Control Entity
MM: Mobility Management
SDS: Short Data Service
SS: Supplementary Services

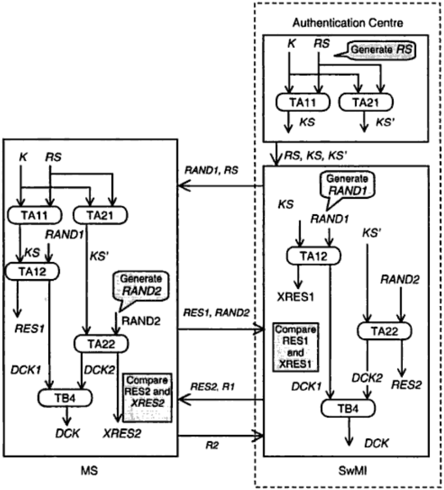
TETRA Security

- Once again all security features optional, like in GSM
- Security features include
  - Authentication
  - Air interface encryption
  - End-to-End encryption
  - Over-the-air re-keying (OTAR)
  - Remote locking of stolen devices
- Not all handsets support all features
- Key material can be stored in handset flash or in SIM

TETRA Authentication

- Authentication messages part of Mobility Management (MM)
- Based on secret User Authentication Key (UAK) in SIM, generating Authentication key K by use of Algorithms TB1, TB2 or TB3
- Supports three modes
  - Authentication of user by infrastructure (TA11, TA12)
  - Authentication of infrastructure by user (TA21, TA22)
  - Mutual authentication (four-pass, TA11, TA12, TA21, TA22)

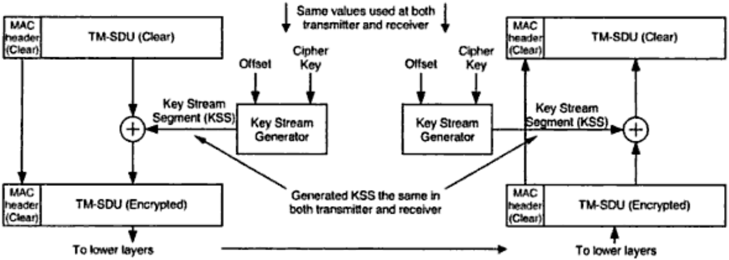
TETRA Authentication



TETRA Air Interface Encryption

- Like GSM: Encrypts only the air interface, not the core network
- Unlike GSM: Not between L1 and L0 but inside the upper MAC layer
    - Thus, no idle frames with known plaintext
    - Thus, no redundant information due to FEC before crypto
- Encryption happens with different keys (SCK, DCK, CCK, GCK, MGCK)
- IV is concatenation of hyperframe, multiframe, frame and slot number

TETRA Air Interface Encryption



TETRA Encryption Keys

- SCK (Static Cipher Key)
  - pre-shared key, used in networks without authentication
  - up to 32 possible keys, selected by SYSINFO.
- DCK (Derived Cipher Key)
  - Generated by authentication procedure (like GSM A3/A8)
  - different for each user
- CCK (Common Cipher Key)
  - Generated by infrastructure and distributed to MS through DCK-encrypted connection using OTAR
  - Used for group calls within one location area
- GCK (Group Cipher Key)
  - Generated by infrastructure and distributed to MS through DCK-encrypted connection using OTAR
  - Used for specific protected groups
- MGCK (Modified GCK)
  - GCK modified by CCK

TETRA Encryption Algorithms

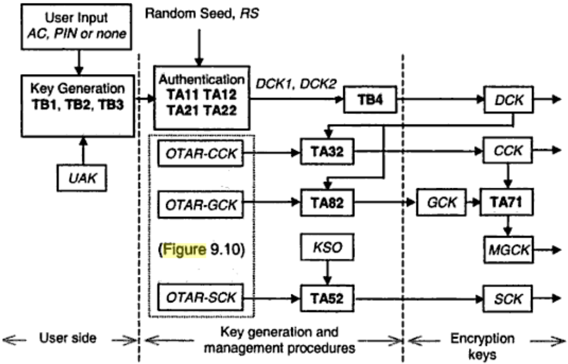
There are 4 specified TETRA Encryption Algorithms (TEA):

- **TEA1** generally available, original algorithm, relaxed export
- **TEA2** for public safety users in Schengen + EU countries
- **TEA3** for public safety users elsewhere
- **TEA4** generally available, reflects relaxed 1998 Wassenaar arrangement

It is assumed that at least original ciphers are 80-bit stream ciphers. None of them have ever leaked publicly!

TETRA Air Interface Encryption

Keys and Algorithms



OTAR-CCK	*CCK* sealed with *DCK* and received over the air interface
OTAR-GCK	*GCK* sealed with *DCK* and received over the air interface
OTAR-SCK	*SCK* sealed with *KSO* and received over the air interface
KSO	a session key for OTAR, derived from a key securely distributed to MSs.

Note: Algorithm names are shown in **bold**, e.g., **TB1, TA31, TA52**, etc.

Is it really secure?

Given all those security features, is TETRA really secure?

- much better than GSM
- however, all security again optional
- security of a given network depends on its configuration
- reality is sad: Government networks secure, private networks insecure
- vendors to blame
  - 200 EUR cost increase in handset for crypto
  - authentication center in core network very expensive

Case Study: tetra-hamburg.de

Seit Beginn der Hauptsaison 2007 ist auf den Alsterschiffen der ATG ALSTER-TOURISTIK GMBH ein neues digitales Bündelfunksystem in Nutzung.

Die Sicherheit der Fahrgäste auf ihren Ausflugsfahrten steht dabei im Vordergrund.

Im Gegensatz zum bisher genutzten Funksystem ist die Funkverbindung digital und somit abhörsicher.

Case Study: tetra-hamburg.de

- public tetra network available for paying users (like cellular carrier)
- by DFP TETRA Hamburg Ges. fuer Digitalfunk mbH
- website claims it is secure against eavesdropping *because it is digital*
- the network does not use any form of TEA encryption
- all signalling, voice, SDS and packet data transferred in plaintext
- digital radio receiver + protocol decoder sufficient for eavesdropping

Case Study: BVG - Berlin subway

- private TETRA network for Berlin subway system (BVG)
- incompatible with bus and tram radio (TETRAPOL) of BVG
- almost no publicly available information, except some 2 press releases when they made big equipment purchasing deals
- the network does not use any form of TEA encryption
- all signalling and voice data transferred in plaintext
- digital radio receiver + protocol decoder sufficient for eavesdropping

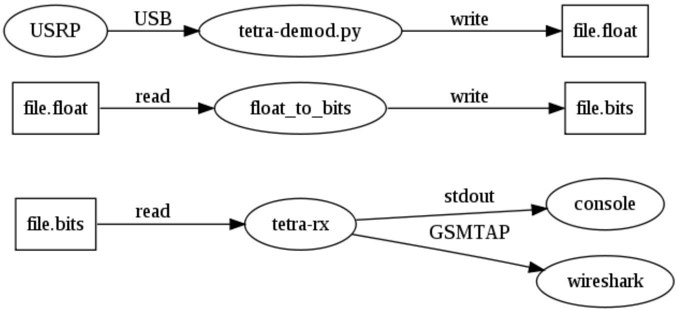
SDS - Short Data Service

- SDS can be compared with GSM/UMTS SMS
- short messages of up to 140 bytes length
- everything like GSM, but not 100% identical

TETRA SNDCP - Packet Data

- SNDCP (Sub-Network Dependent Convergence Protocol)
- facilitates packet switched services like IPv4 over TETRA
- leverages the GPRS network architecture and protocols
- PDP Context to APN (like GPRS)
- very slow unless both base station and handset support QAM modulation

Osmocom TETRA Demodulator



Osmocom TETRA Demodulator

- 1:1 code re-use from APCO-25 Software receiver project
- Hierarchical block fully based on gnuradio blocks
    - Root-raised cosine filter
    - M-PSK receiver block
    - Costas Loop for carrier tracking
    - Muller&Muller synchronizer
    - output: Float value between -3 and 3 in units of pi/4

Osmocom TETRA PHY

The burst synchronizer (`tetra_burst_sync.c`)

- First acquires the Sync Burst training sequence by correlation
- Later locks on Normal Burst (NB) training sequences
- Splits actual payload sections out of training sequences,

The burst generator (`tetra_burst.c`)

- puts together various bursts such as NB, SB and others
- calculates phase alignment bits
- used to test receiver code

Osmocom TETRA lower MAC

Receive Side

- Receives bursts from PHY layer
- Applies the following operations depending on burst type
  - De-scrambling
  - De-Interleaving
  - De-Puncturing (RCPC code)
  - Viterbi decoder (RCPC code)
  - Compute + Verify CRC-16
- Recover TETRA Time (frame number) from SYNC burst
- Hands decoded payload data to upper MAC

Osmocom TETRA lower MAC

Transmit Side

- Receives payload from upper MAC
- Applies the following operations depending on burst type
  - Append tail bits
  - Compute CRC-16
  - Convolutional encoder (RCPC code)
  - Puncturing (RCPC code)
  - Interleaving
  - Scrambling
- Hands decoded payload data to PHY

Tx is currently only used in testing the Rx code

Osmocom TETRA upper MAC

- Rx-only
- Not a complete implementation, just to decode SYSINFO, ACCESS-ASSIGN and (more and more) other bits.
- Mainly a proof-of-concept to ensure PHY and lower MAC work

Osmocom TETRA LLC

- Rx-only
- gathers and de-fragments LLC fragments of MAC PDUs
- offers them to higher layer protocols like MM, CMCE, SNDCP
- Mainly a proof-of-concept implementation, nothing fancy

Osmocom TETRA speech frame export

- Not in the public git repository yet
- simply identifies and dumps speech frames to a file
- data still needs to be de-compressed
- luckily, ETSI specs come with C reference code for the speech codec, so we can generate raw PCM files that we can play back

Osmocom TETRA via GSMTAP

- The GSMTAP pseudo-header has been extended for TETRA
- Change is backward-compatible with existing GSMTAP
- current version of libosmocore supports extended GSMTAP
- OsmocomTETRA `tetra-rx` contains GSMTAP output support

wireshark TETRA integration

- TETRA messages are unaligned bit-fields, full of variable-length and optional parts
- Writing manual decoding/encoding routines is tiresome and error-prone
- Beijing Institute of Technology has developed wireshark dissectors based on describing TETRA messages as ASN.1 PER (described in IEEE paper)
- We contacted them and they were willing to release their code under GNU GPL
- Zecke has extended it with GSMTAP support it has been included in wireshark mainline

Transmitting TETRA

- The lower MAC and PHY code exists and is proven
- OP25 project contains modulator for pi/4 DQPSK
- Combining the two should render simplistic TETRA transmitter
- Sending continuous sequence of BSCH in SB and BNCH in NB comprises valid beacon and should allow handsets to lock on the signal
- So far no time to experiment with it
- Could be first step in SDR TETRA Base Station

Thanks

Thanks to

- Dieter Spaar for discovering the APCO25 demodulator and his work on speech decoding
- Sylvain Munaut for implementing our own Viterbi decoder
- Holger Freyther for his work on CRC, Shortened Reed-Muller and wireshark
- horiz0n for providing sample captures of TETRA radio traffic

Further Reading

- http://tetra.osmocm.org/
- http://www.tetramou.com/
- http://www.etsi.org/website/Technologies/TETRA.aspx
- http://www.tetramou.com/uploadedFiles/About_TETRA/TETRA%20Security%20pdf.pdf
- http://www.tetrawatch.net/
- *Digital Mobile Communications and the TETRA System* by John Dunlop, Demessie Girma, James Irvine - Wiley