

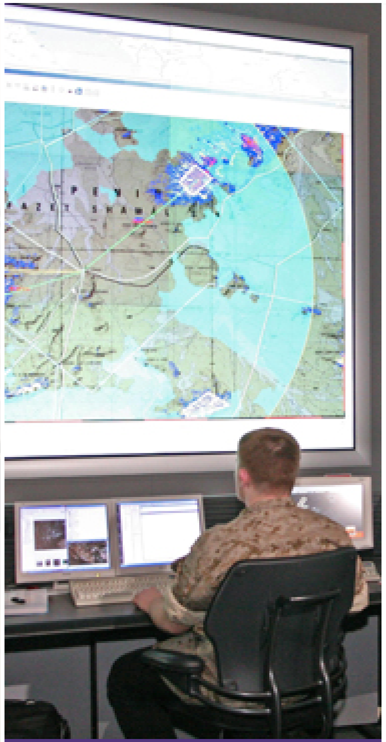

Oriented processing of communication signals for Sensing and disseminated spectrum monitoring

SDR'11 Winncomm, session 6B, Brussels, June 24

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SUMMARY

Introduction – Objectives of sensing and spectrum monitoring

Cognitive Radios and sensing

Spectrum Monitoring, previous realizations, current trends

Merging sensing and disseminated spectrum monitoring

Processing of communication signals

Oriented processing of communication signals

Special case of data-aided processing - Comparative advantages

Practical implementation

Protocols aspects

Network architecture proposal

Requirements for Embedded Hardware and Software

Conclusion

Oriented processing of communication signals…

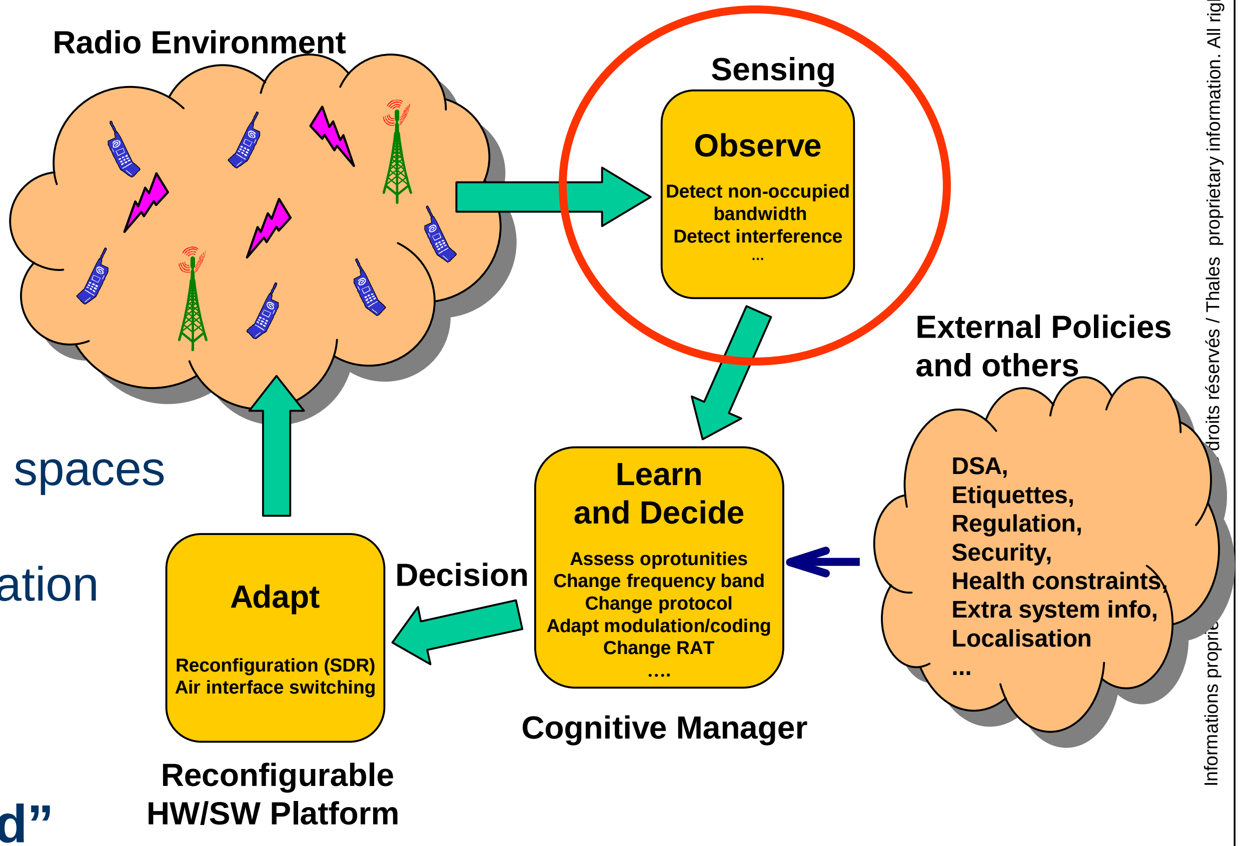
Introduction – Objectives of sensing within Cognitive radios

Sensing is part of the cognitive process

Sensing provides radio information elements to the cognitive manager

- search for free carriers
  for spectrum white spaces
- enhance the radio access
- facilitate interference mitigation

=> Sensing is mainly "communication oriented" "radio access oriented"



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Introduction – Objectives of sensing within Cognitive radios

Some of 2G/3G/4G systems that CR/sensing will have to deal with

System:	Uplink Frequency Band [MHz]	Downlink Frequency Band [MHz]	Channel spacing	Modulation	Max. Output Power
GSM 900 DCS 1800 PCS 1900	890 - 915 1710 - 1785 1850-1890	935-960 1805 - 1880 1930 - 1970	200 KHz	GMSK + 3π/8 QPSK	~ 2W
W-CDMA	890 - 915 1920 - 1980	935-960 2110 - 2170	5 MHz	OCQPSK	0,25 W
LTE	890 - 915 2500-2570	935-960 2620-2690	1,4 - 5 MHz	OFDMA SC-FDMA	0,25 W
WIMAX	2402 – 2480 3400 – 3600 5150 - 5850		10 MHz	OFDM	0,25 W
WIFI	2402 - 2480 5150 - 5850		20 MHz 20 – 80 MHz	OFDM	0,1 W
Bluetooth	2402 - 2480		157 KHz	0.5BT - GFSK	0,01 W
WiGig	57 – 65 GHz		2 GHz	QPSK, QAM OFDM	0,1 W

Source : A Kaiser, GDR Soc Sip Paris tech 10 Mai 2011

Introduction – Objectives of spectrum monitoring

SM is part of the ITU goals & missions of telecommunication administration

- **measure signals**
  - => power
  - => bandwidth
- **search for abnormal signals**
  - => identification
  - => localization

=> SM is mainly "regulator oriented"

SM has to deals with numerous signals and radio environments

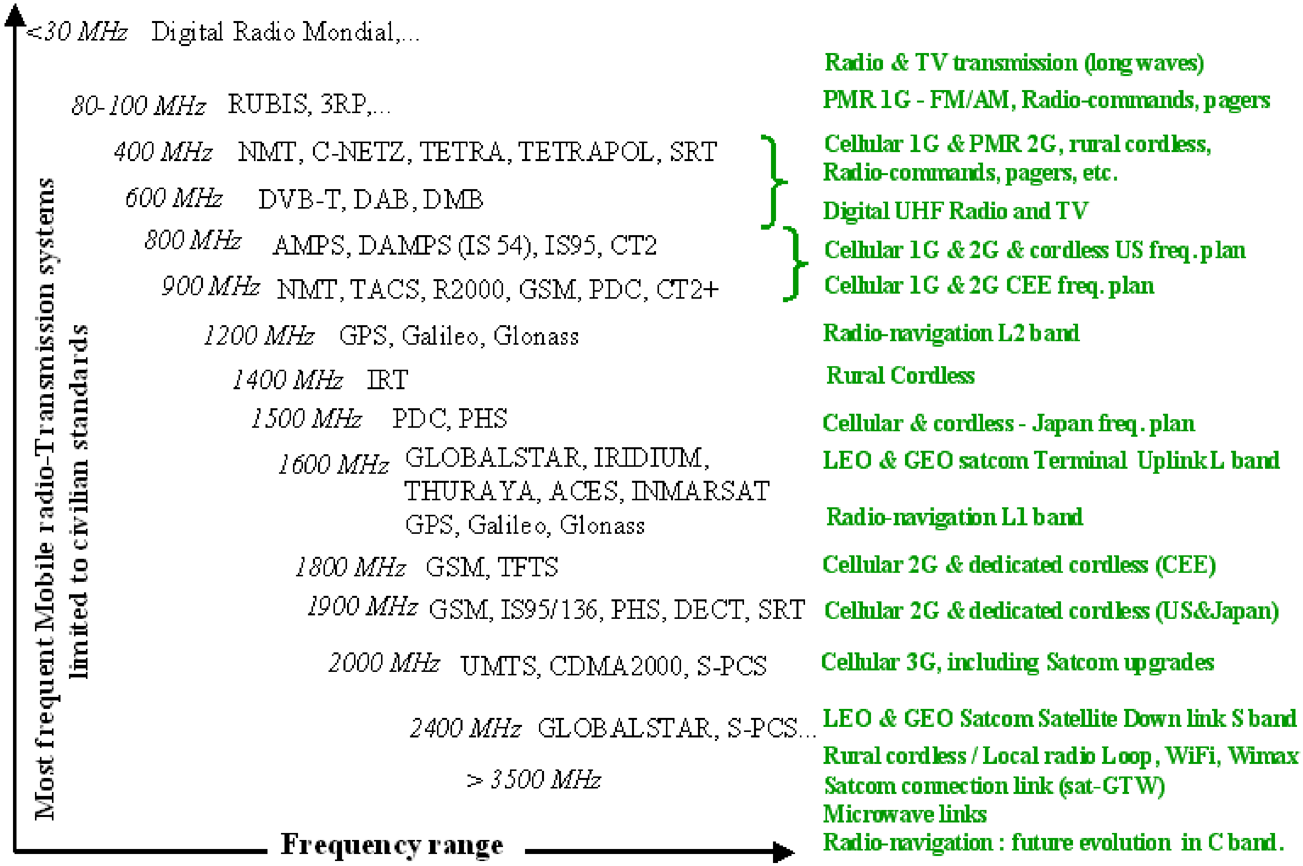


Illustration – Diversity of the communication signals addressed by SM

Single carrier Signals
Multi Tx Signals (MISO; MIMO)

Single carrier Signals
Single Tx Signals

Multi-carrier Signals
(C)OFDM, OFDMA

analogues Modulations

AM

$$x(t) = A(\alpha + K_a m(t))\cos(\omega_0 t)$$

- $m(t)$: **modulant signal (real)**
- K_a: **Modulation index ($0 \le K_a \le 1$)**
- α: **Carrier yes or no (1 or 0)**
- A: **Amplitude**

FM

$$x(t) = A\cos(\omega_0 t + 2\pi\Delta F\int_0^t m(u)du)$$

- ΔF: **Frequency excursion**

Composed

AM-XXX
FM-XXX

Digital Modulations

linear Modulations

$$x(t) = \mathrm{Re}\left(A\sum d_k g(t-kT)e^{j\omega_0 t}\right)$$

ASK
QAM

ASK		OOK
QAM		BPSK
		QPSK
		8PSK
		Π/2 DBPSK
		Π/4 DQPSK
		QAM 8
		QAM 16
		QAM 32
	SQAM	SQPSK
	(OQAM)	(OQPSK)

Non linear Modulations (angular modulations)

$$x(t) = \begin{cases} \mathrm{Re}\left(Ae^{2i\pi h\sum d_k q(t-kT)}e^{j\omega_0 t}\right) \\ \mathrm{Re}\left(Ae^{2i\pi\Delta FT_s\sum d_k q(t-kT)}e^{j\omega_0 t}\right) \\ \mathrm{Re}\left(Ae^{2i\pi h\int_{-\infty}^{t}\sum d_k g(u-kT)du}e^{j\omega_0 t}\right) \end{cases}$$

discontinuouss FSK
CPM

discontinuous FSK	**FSK 2-34**
Continuos Phase Modlations (CPM)	**MSK**
	GMSK
	LRC
	LSRC
	CPFSK (FSK 2-34)

Oriented processing of communication signals…

Illustration – How looks like a National SM system today ?

Monitoring - technical analysis
Signal parameter measurement
Interférence analysis

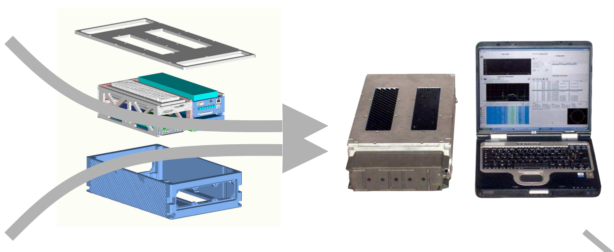
Direction Finding (DF)
Localization
Spectrum occupation analysis

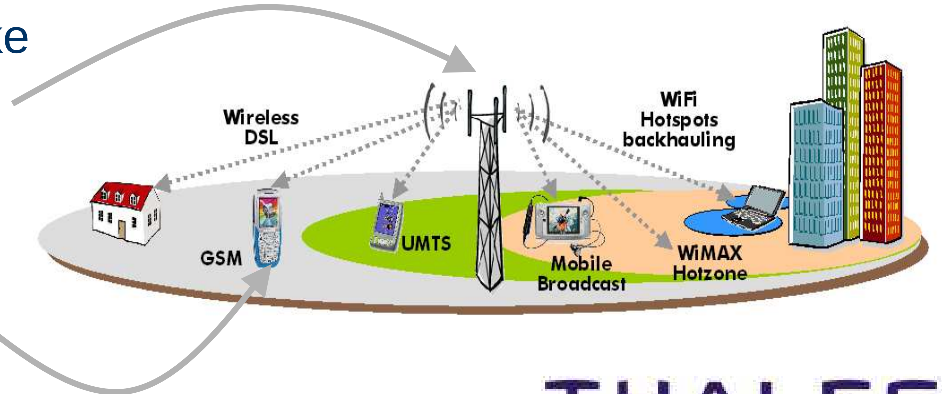
Evolution – What are the current trends of SM systems ?

- **Commercial services at higher frequencies**
- **Dynamic frequency usage**
  (dynamic access, opportunistic access)
- **Dense spectrum occupancy**
- **Frequency sharing**

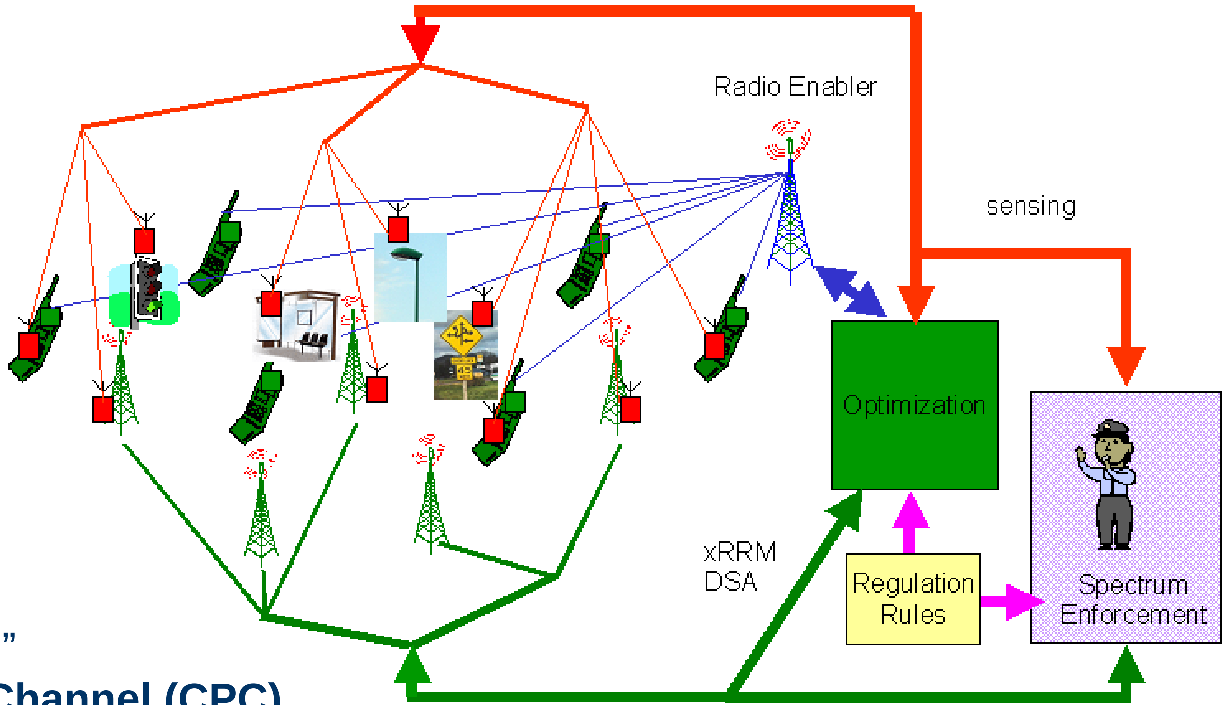
- **SHF monitoring and DF, short range urban stations**
- **Alternative loc. techniques (TDOA) and HR DF techniques**
- **Use of disseminated sensing with databases for radio electric environment assessment and evaluation of spectrum opportunities, in addition to spectrum monitoring**

Integration is a stake





Evolution – Previous realizations relevant to disseminated/distributed SM



I/ Project URC

"Urbanisme des
Radio Comunications"
Pôle de compétitivité
System@tic
Ile de France

II/ IST Project E^{2}R

"End to End Reconfiguration"

Study of Cognitive Pilot Channel (CPC)
Definition of network architectures / protocols relevant to sensing

III/ Projects relevant to embedded metrology:

ANTIUM (IST 2003): 3G/UMTS & DVB-T, SEMAFOR (WiMax), QOSMOS: LTE.
RECOSS: disseminated miniaturized SM sensor (laptop size)

Evolution – Current trends of SM towards dissemination

- **Initiative ANFR/Thales : NEW QUESTION ITU-R [SPEC-MONIT-EVOL]/1**
  - What are the new considerations for monitoring of radiocommunication systems that are based on new technologies?
  - What are the new approaches that may be required in terms of organisation, procedures and equipment to monitor systems based on future radiocommunication technologies?
  - What are the needs for administrations in order to implement the new approaches to monitor systems based on future radiocommunication technologies?
- **Radio Spectrum Policy Group SE43(11)Info01 « Opinion on Cognitive Technologies »** (relevant to disseminated SM)
- **CEPT SE43(11)04 "Combination of geo-location database and spectrum sensing techniques"** (relevant to geo-referenced sensing)
- **Version 2011 of the "Spectrum Monitoring Handbook"**
- **Revision of recommendations REC ITU-R SM.1600 "Technical identification of digital signals" and REC ITU-R SM. 1598 "Methods of radio direction finding and location on time division multiple access and code division multiple access signals".**

Why merging sensing and disseminated spectrum monitoring ?

I/ Shared needs of both sensing and SM applications

Dealing with highly diverse and complex radio environment
Require some recognition capabilities of radio-signals
Datas collected at radio interface have to be sent to "upper layers"

II/ Weakness of "heavy SM sensors"

In indoor cases
Face to dense envirT (urban centers)with interference & multi-paths
Face to Tx power control (sensitivity)

III/ Radio + computing performances of futures cognitive radios

Coverage of several frequency bands in a very wide frequency range
High rate and high dynamic sampling
Embedded memory + computing + communication protocols
Inside the real measurement field

=> A natural trend is to merge SM and sensing capabilities within the same devices…

Why merging sensing and disseminated spectrum monitoring ?

… **A natural trend is to merge SM and sensing capabilities within the same CR → Alternatives**

I/ Taking the direct benefit of CRs' sensing for SM

Sending sensing results from CR to SM centers
Reliable indication/alert of local spectrum quality
Provides a large scale geographical coverage of the spectrum
Geo-referenced sensing => leads to maps of coverage and "hot spots", etc.

II/ CR performing in-situ analyses dedicated to SM applications,

Pre-analyses of the spectrum by the terminal itself
Sending SM' results to SM centers + additional signal samples
(in addition to sending sensing results to Cognitive Manager)

III/ CR collecting signal samples on the radio link

Store and send them to the SM centers
Off-line delayed transmission during "idle modes"

Requires dedicated secured transmission procedures

Processing of communication signals - general

I/ Stand Alone processing

When you have no knowledge at all

=> first step is blind procedure

=> 2nd step is oriented processing when you have pieces of info. from 1st step

"Exotic" signals or military signals

II/ Oriented processing,

When you have partial knowledge (semantic description of signal)

When you have data bases of signal characteristics

=> expert approach

Most of civilian signals

III/ "Data aided" or cooperative processing

Special case of oriented processing

When you have complete information of parts of the signal

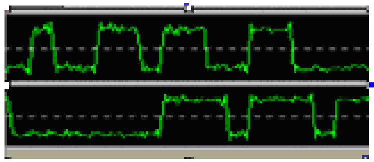
(GSM middambles, UMTS scrambling codes, DVB/Wimax/LTE pilots, etc.)

When you have data bases of signal sequences + low search combinatory

=> inter-correlation / matched filter approach

Many civilian Digital standards

« Philosophy » of oriented processing of communication signals



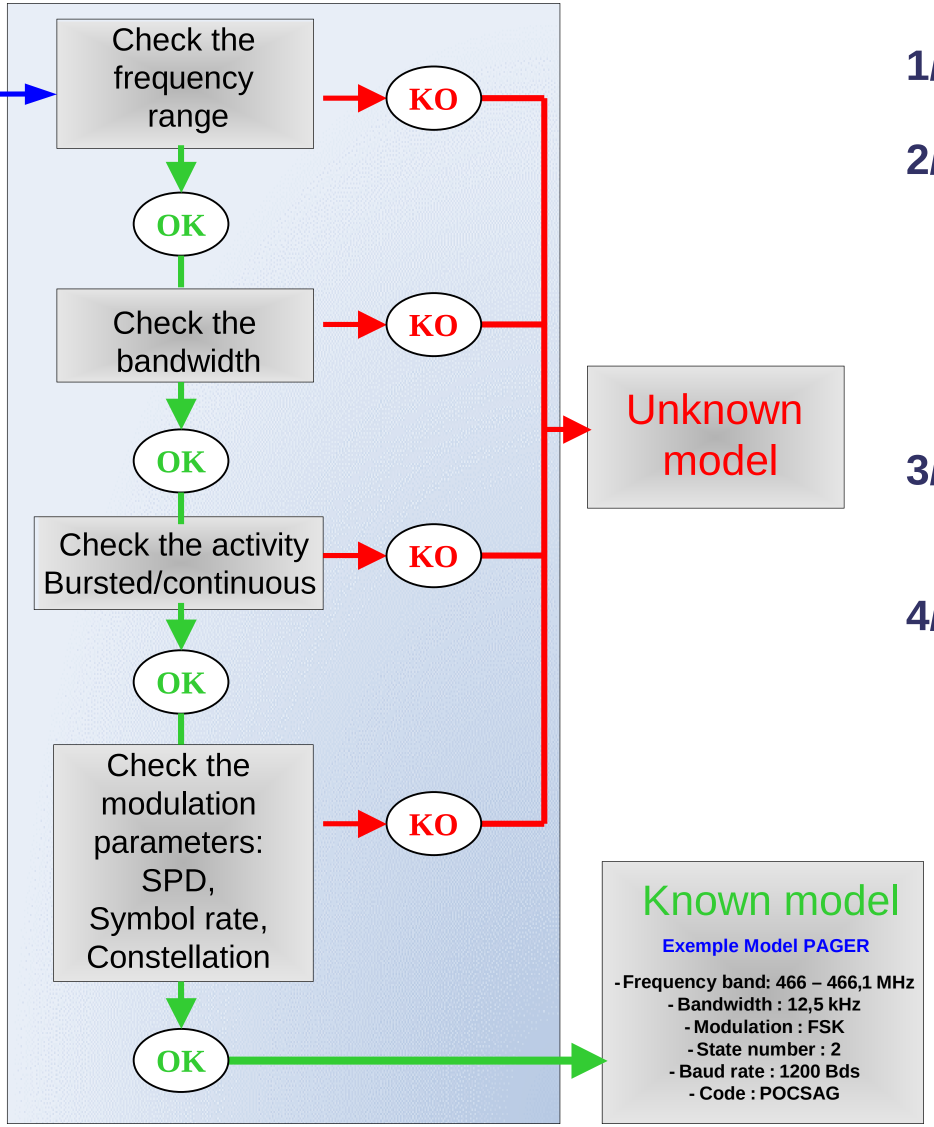
Example of Input Signal

Model 1: PAGER
- Frequency band: 466 – 466,1 MHz
- Bandwidth : 12,5 kHz
- Modulation : FSK
- State number : 2
- Baud rate : 1200 Bds
- Code : POCSAG

Example of semantic model from data base

⇒ **Step by step oriented analyses**
+ checking of semantic characteristics

⇒ **Very efficient when dealing with digital modulations**



1/ «expert system» type

2/ progressive estimators
- signal enveloppe,
- modulation parameters
- code parameters

3/ from general to dedicated

4/ model comparison at each step

=> leads the following processing

=> reduces combinatory

Oriented processing of communication signals

A/ Wave Form Structure characterization

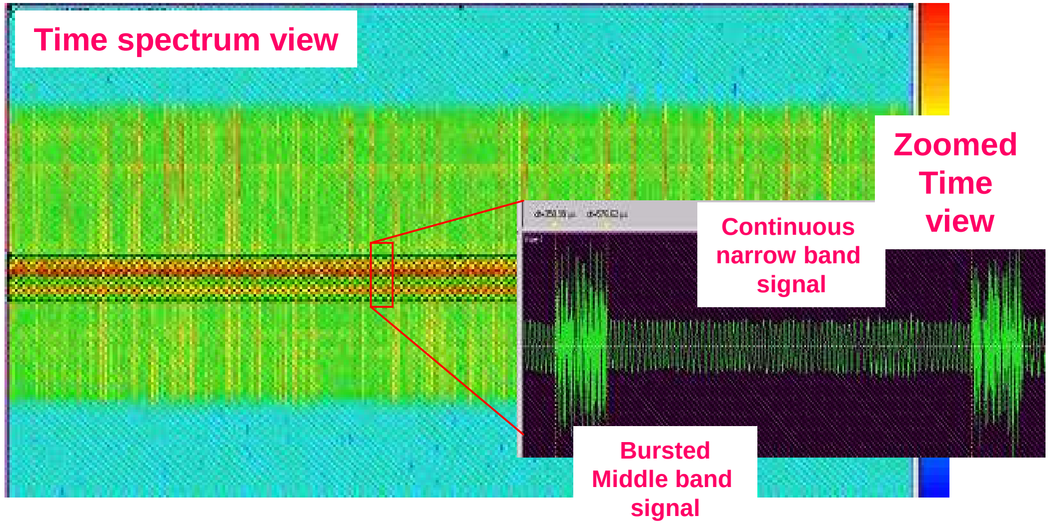
Narrow band / wide band signal

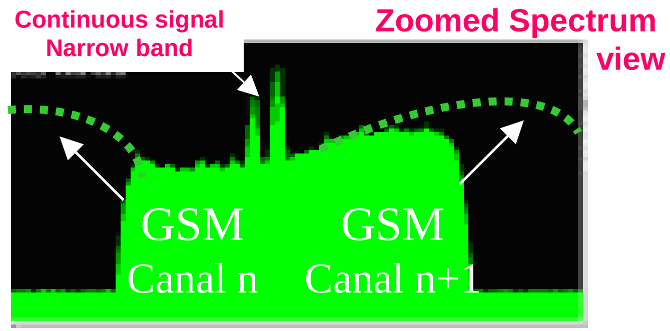
Continuous / bursted signal

Frame characteristics

Synchronization characteristics

Radio Access protocol characteristics (FDMA,TDMA,CDMA, ...)





Oriented processing of communication signals

B/ Estimation of modulation parameters

Carrier center frequency

Signal bandwidth, Symbol rate,

Number of states, Constellation

Shift (FSK and CPM), FM depth, AM index…

Signal demodulation

Single carrier AM/FM,CPM, PSK, QAM, FSK…

Multi carrier OFDM, etc.

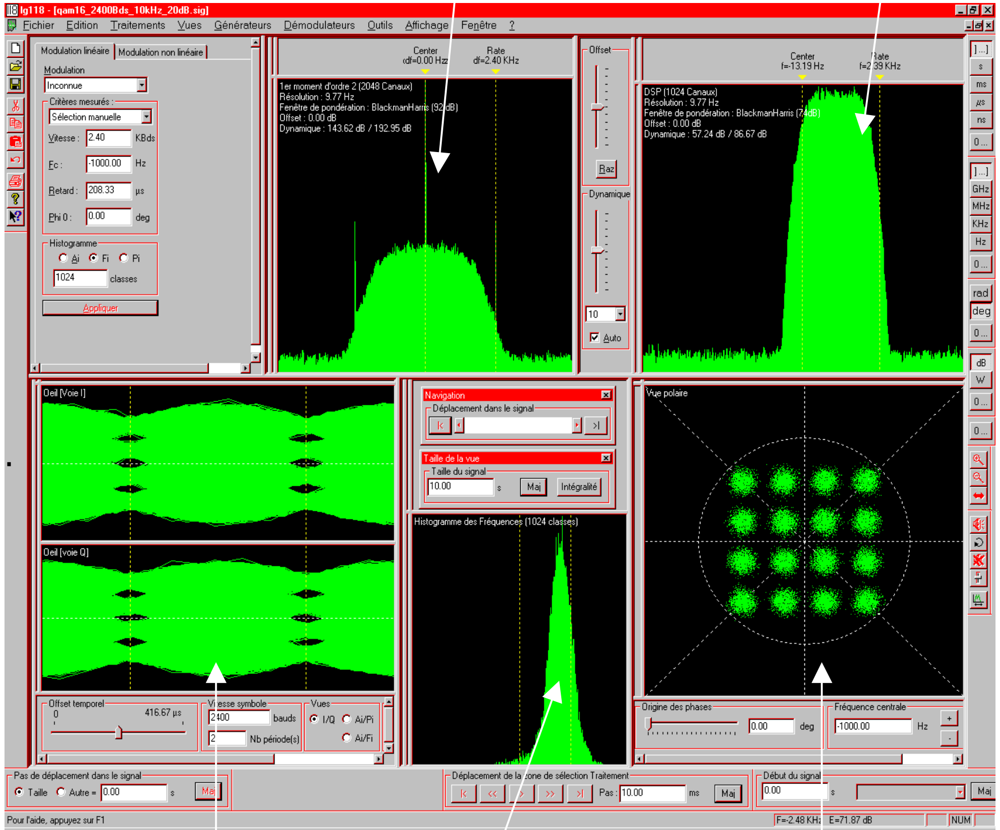
Analyses of coding scheme

Signal identification

Data bases, semantic descriptions.

STATISTICAL MOMENTS , Spectrum of non-linear transforms of the signal, etc.

SPECTRAL DENSITY POWER



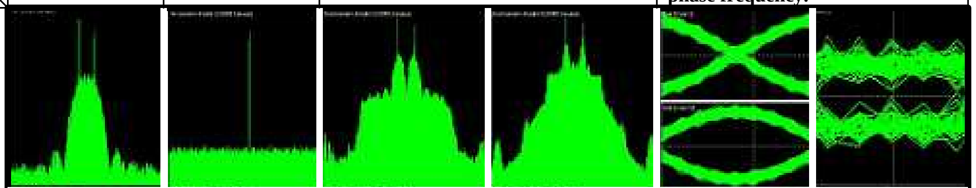
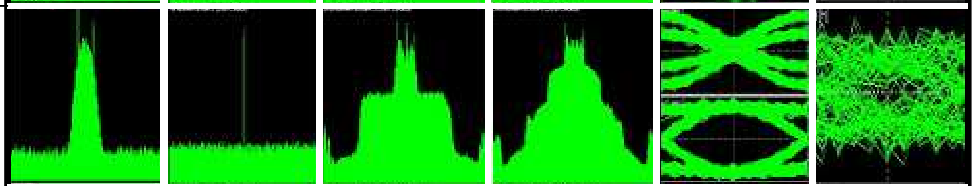
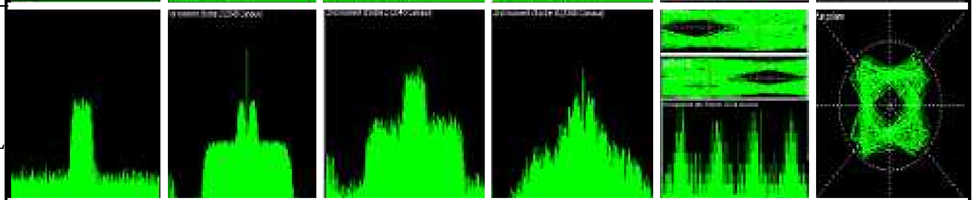
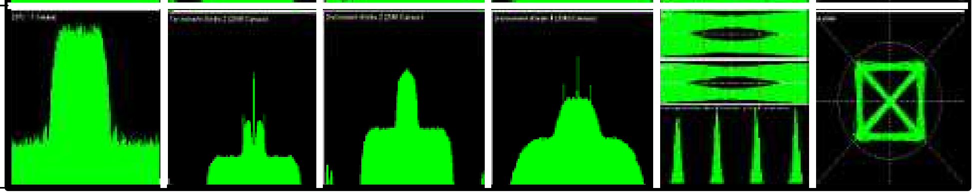
EYE DIAGRAM

OTHER SIGNAL STATISTICS HISTOGRAMS,tetc.

AMPLITUDE PHASE POLAR DISPLAY

Oriented processing of communication signals

Regular statistical estimators leading to measurement of modulation parameters

Technical purpose	Power measurement	Estimation of center frequency	Estimation of Symbol rate		Synchronization of symbol + demodulation	
Statistical estimator / Signal example	Spectrum Power Density	Spectrum 1^{st} moment order 2 $E[\|x\|^2]$	Spectrum 2^{nd} moment order 2 $E[x^2]$	Spectrum 2^{nd} moment order 4 $E[x^4]$	Eye Diagram & Histograms I/Q, Amplitude phase frequency.	Eye Diagram & Polar Diagram
FSK2 Ind. 1 SNR 20 dB "PMR like"						
GMSK Ind. 0,5 SNR 20 dB "GSM like"						
O-QPSK Roll off 0,25 SNR 20 dB "CDMA 2000 UL like"						
QPSK Roll off 0,25 SNR 20 dB "UMTS like"						

Oriented processing of communication signals

Advanced statistical estimators leading to measurement of modulation parameters

- **Cyclic Correlations:**
  - First moment order 2:

    2D Fourier Transform (t->α)

    of the correlation

    $R_{1x}(t,\tau)= E[x(t)\, x^*(t+\tau)]$
  - Second moment order 2:

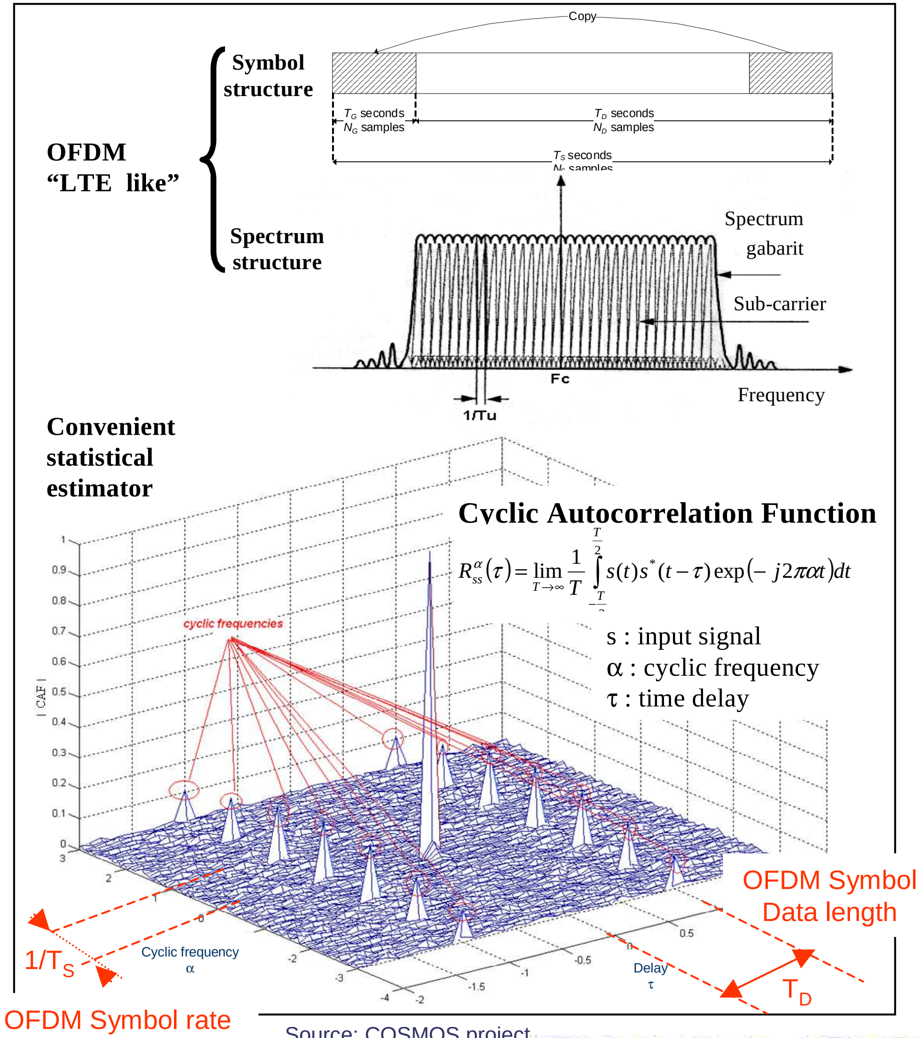
    2D Fourier Transform (t->α)

    of the correlation

    $R_{2x}(t,\tau)= E[x(t)\, x(t+\tau)]$
- **Extracts the periodic statistical characteristics of the signal**

  (guard time repetition=>OFDM symbol length)
- **3D representation:** Level versus delay τ, cyclic Frequency α

  and 2D cuts



Source: COSMOS project

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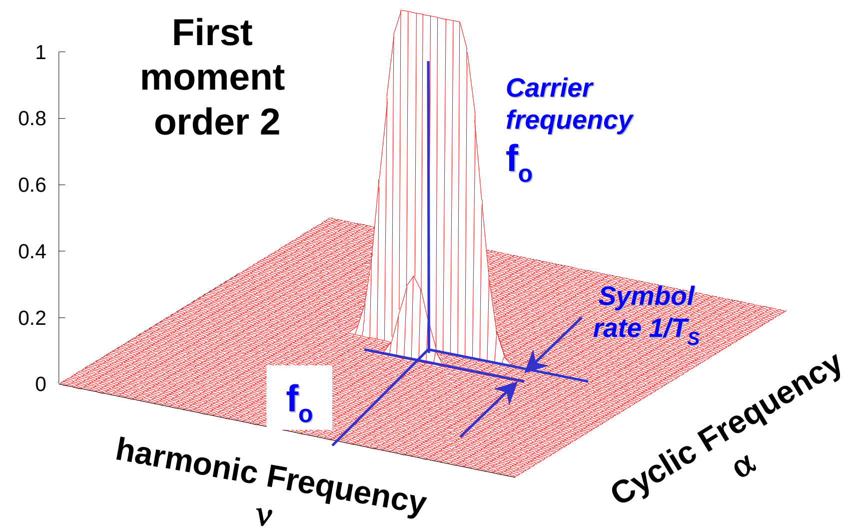
Oriented processing of communication signals

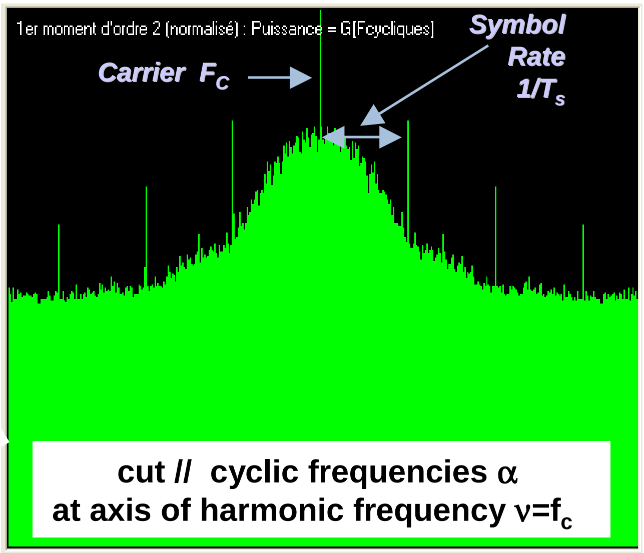
Advanced statistical estimators leading to measurement of modulation parameters

- **Spectrum Correlations**:
  - First moment order 2: 2D Fourier Transform (t->α, τ–>ν) of correlation $R_{1x}(t,\tau)= E[x(t)\, x^*(t+\tau)]$
  - Second moment order 2: 2D Fourier Transform (t->α, τ–>ν) of correlation $R_{2x}(t,\tau)= E[x(t)\, x(t+\tau)]$

- **Extracts characteristics of periodic statistical properties** of the signal (carrier, modulation rate) **without any a priori knowledge (exotic signals)**

- **3D representation and 2D cuts:** Level versus { harmonic Frequency ν / cyclic Frequency α }





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Oriented processing of communication signals…

Special case of data aided techniques

"Direct" Intercorrelation

- Early detection and recognition
- Protocol structure recovery

Direct identification

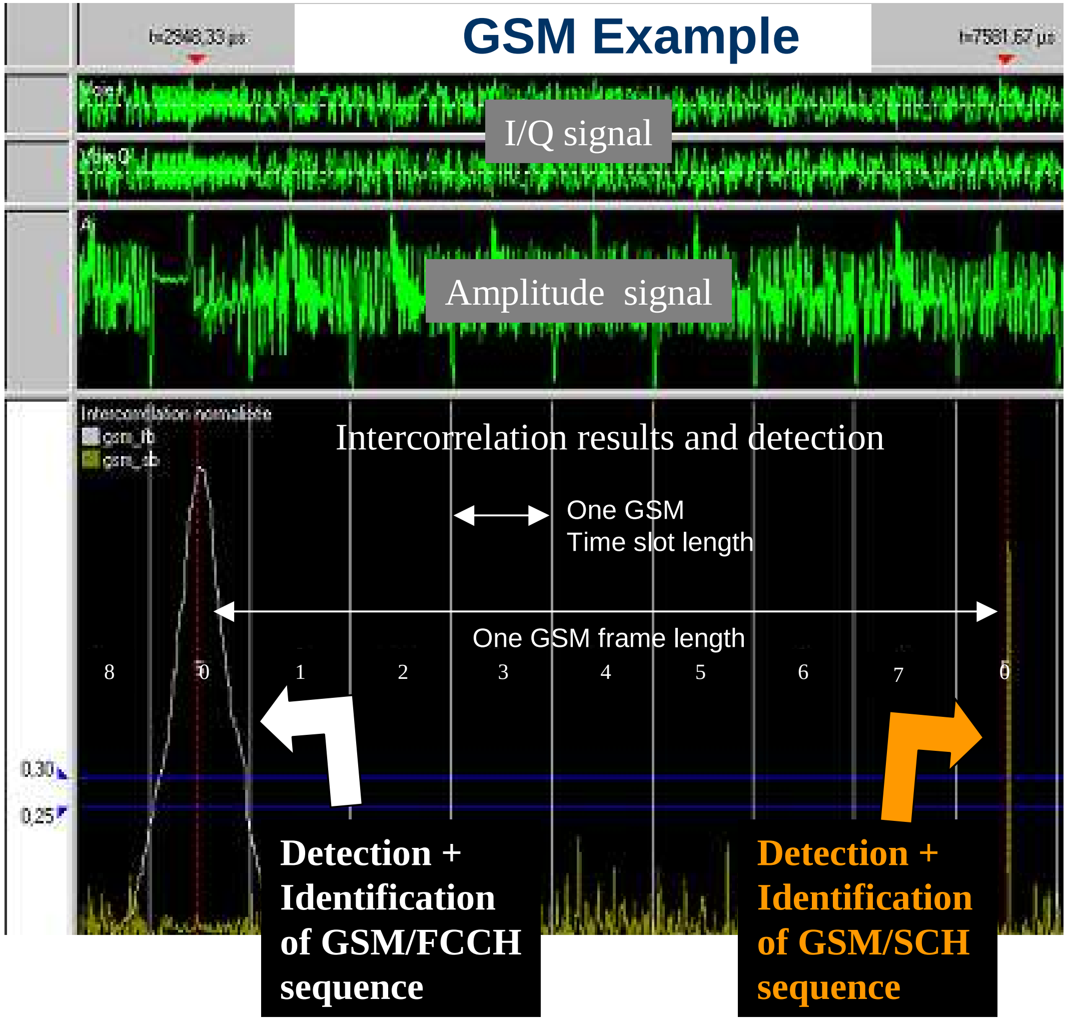
- Modulation parameters
- Radio access protocol
- Set of coding schemes

Comparative advantages

> When Low combinatory and low Doppler
  => reduced complexity
  => real Time OK

> Processes low powers signals

> Processes medium ratios for signal to noise+interference



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Practical implementations – protocol aspects

Source : E[2]R project, White Paper Nov 2007

0- Switch-on and initialization

Location determination

Detection of CPC

1- Exploitation of the DL "public advertiser"

Extraction of the information relevant to the mesh where the mobile is located

Local check and upgrade of the signal model data base

2- Sensing and Measurement of radio link

Priority to "oriented analyses"

with the help of upgraded data-bases

Shortcut with data-aided processing when suitable

Back-up stand-alone analyses for failure cases

+ recording of signal samples for further deeper analysis

3- Reporting through dedicated radio-links

Sensing : radio measurements

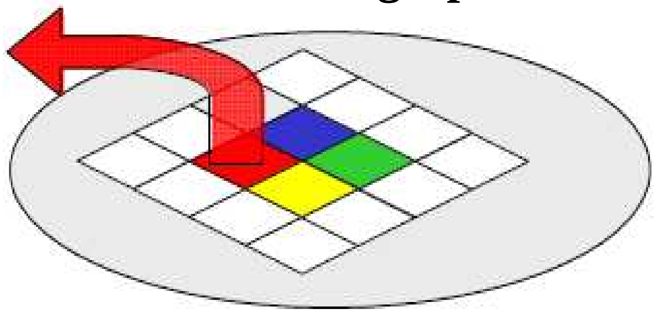
→ cognitive manager / network

SM : radio measurements + signal samples

→ towards SM centers

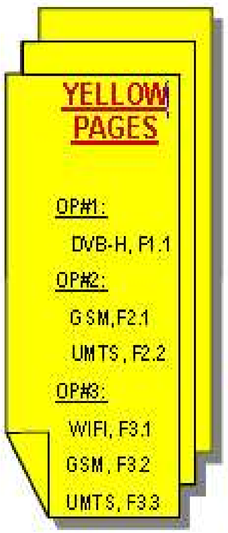
CPC information

- mesh dependant
- contains relevant updated data describing the way spectrum is locally used in mesh #i

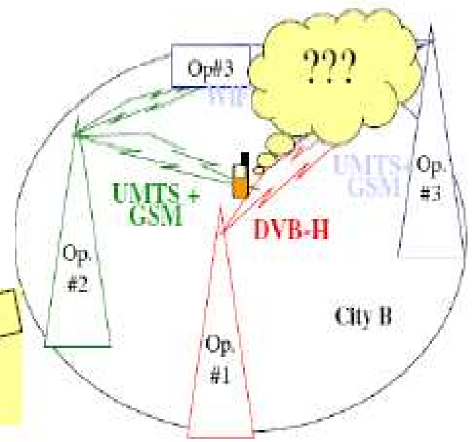


CPC mesh organization

CPC DL "public advertiser" concept



At switch on:
The terminal does not know the "current" configurations of the various networks, neither the frequency bands allocated to the Radio Access Technologies (RAT)



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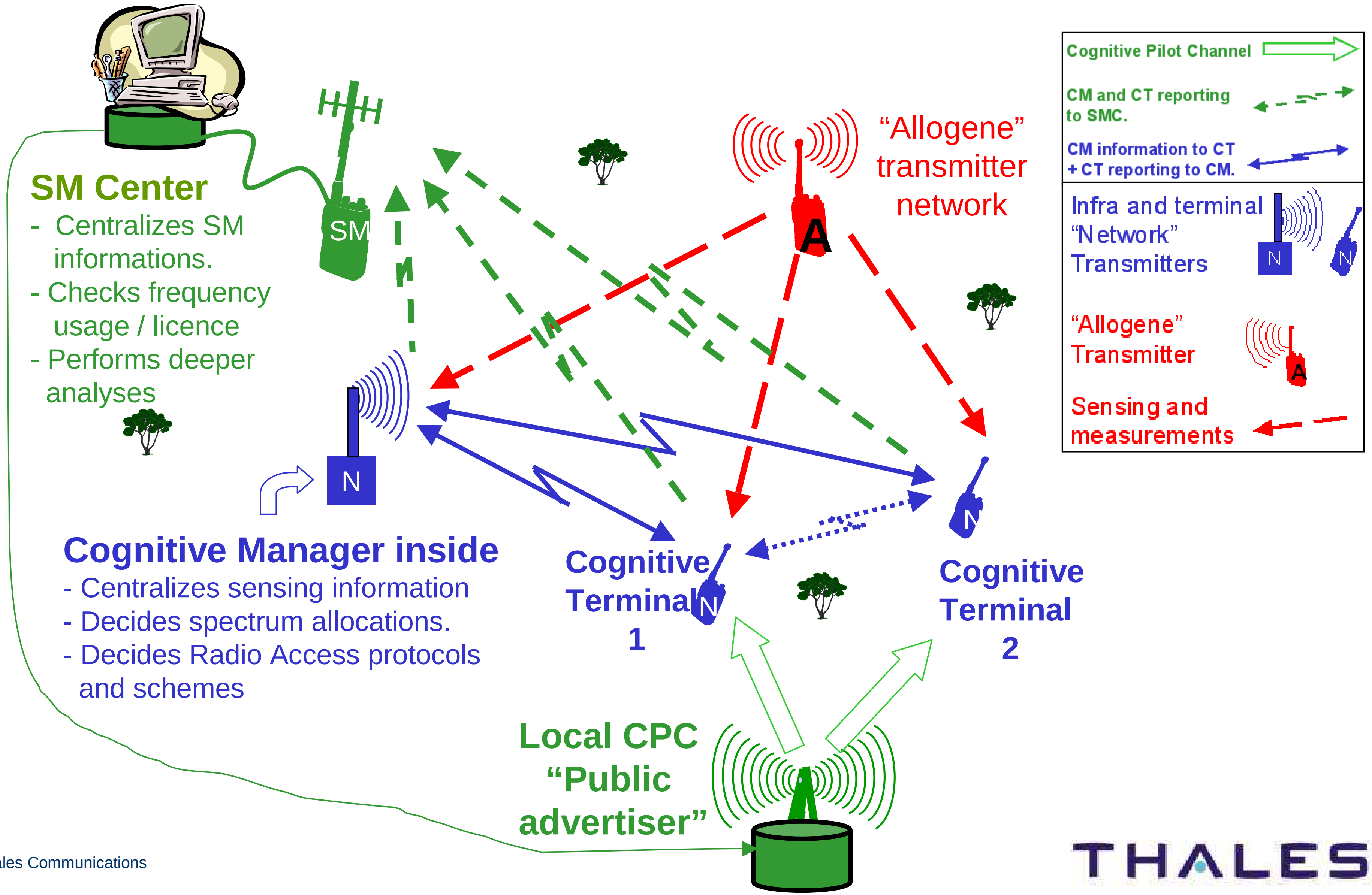
Oriented processing of communication signals…

Practical implementations – network architecture considerations



Practical implementations – Requirements for Embedded Hardware and Software

“Regular” radio performance (noise factor, dynamic, sensitivity)
no specific requirement / CR developments

Convenient signal durations : processing of 50 ms to 100 ms

Convenient bandwidths : processing of 10 MHz to 40 MHz bandwidth

Real time constraints : light
sensing recurrence from 1 to 10 s, even more

Memory storage : a few GBytes

Transmission of sensing results : no specific requirement / CR developments

Transmission of signal samples : delayed during “idle modes”

BUT : necessity for added dedicated secured transmissions of sensing info and of SM info toward SM centers

Conclusions – perspectives

I/ Several technical arguments in favor of

Merging sensing and disseminated Spectrum Monitoring applications within CR

Implementation of oriented signal processing for both sensing and SM:

- Analyses performances are largely upgraded,
- Signals are identified and measured in the same process
- Computations are often reduced.

II/ Relevant requirements should meet the current standardizations 4G trends

No added radio performances are required for cognitive terminals.
The added complexity should be compatible with future embedded computers
Only dedicated secured transmissions of sensing/SM info are required

III/ Oriented processing of radio-communication signals appears as a major technical opportunity for future CR and for RAT

What about including oriented signal processing in the standardization efforts for 4G radio networks ?