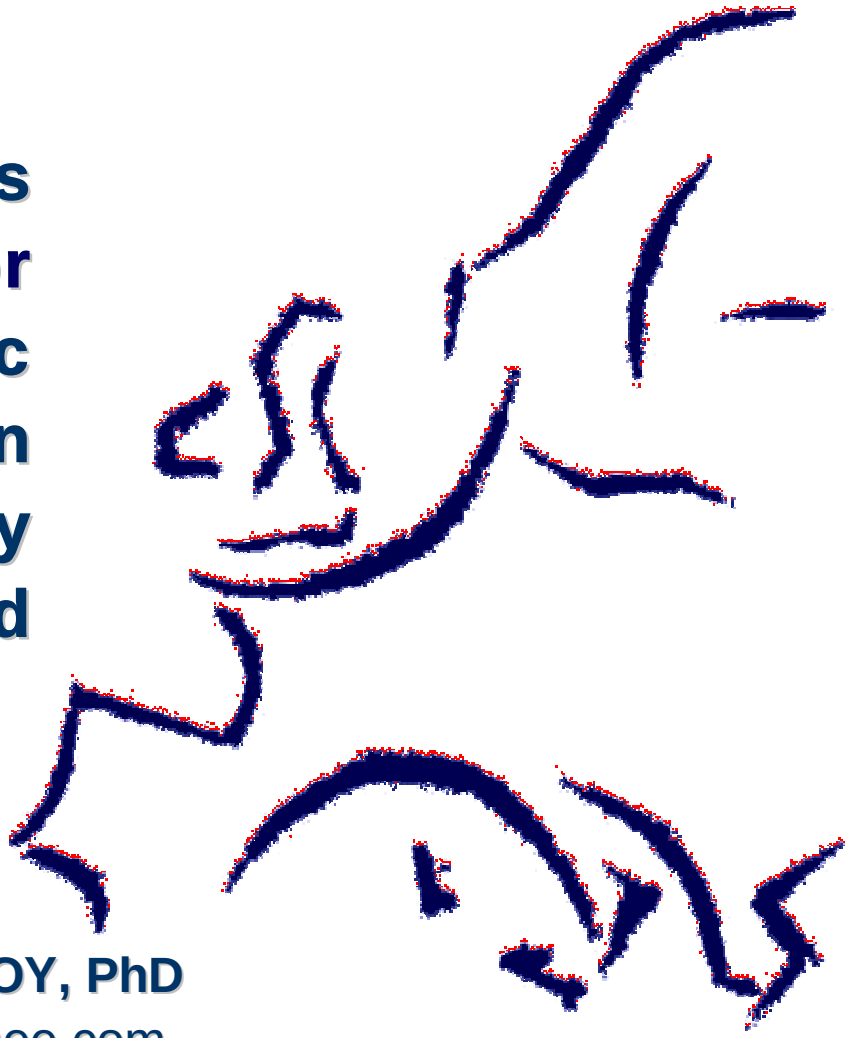
Information Technology Center Europe
Telecommunications Laboratory

HW and SW Architectures for Over-The-Air Dynamic Reconfiguration by Software Download



a proof of concept by lab experimentation

Christophe MOY, PhD
moy@tcl.ite.mee.com

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Outline

- Mitsubishi Electric Telecom
- Motivations for Software Radio
- Motivations for reconfiguration
- HW generic platform
- Digital radio
- SW architecture for reconfiguration
- Demonstration
- Roadmap
- Perspectives
- SDR projects
- Conclusion

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Mitsubishi Electric Telecom

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Mitsubishi Electric Telecom

- **Infrastructure**
  - **PDC, PHS**
  - **and future systems**
- **Mobile terminals**
  - **GSM/GPRS, PDC, i-mode, Foma (3G)**
  - **and future systems**
- **Corporate R&D**
  - **labs in Japan, US and EU**
  - **Information Technology Europe:**
    - VIL: Video and broadcast (UK)
    - TCL: Telecoms (France)
      - Software Radio department

Huge internal R&D effort on future wireless technologies

Software Radio (SWR)

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Motivations for Software Radio

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Motivations for Software Radio

- **A new way to design radio systems (both terminals and BTS)**
  - **economic in the long term**
    - mono-HW platform for several products
    - shorter design time (more SW design)
    - flexibility (last minute adaptation)
  - **easier to manage after selling**
    - updates, bug fixing
- **New radio capabilities**
  - **for the service providers' benefit**
    - maintenance, service quality, performance enhancement (remotely)
  - **answer users demand (for terminal)**
    - personalization, differentiation
- **A solution to multi-standard**

Motivations for reconfiguration

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What is Software Radio?

- **As much as possible of a radio system in digital and if possible in SW**
- **In order to benefit from the digital domain**
  - **design techniques**
    - computer aided design tools...
  - **technologies**
    - low power, small size...
  - **usual advantages for telecommunications**
    - robustness, protection capabilities, capacity...

Not only an evolution, but a new capability

  - **reconfigurability**
    - processors, reconfigurable HW, parameterizable ASICs

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Requirements for reconfiguration

- **HW architecture**
  - **computing power (potential)**
    - multi-processing (SoC or distributed)
    - efficient communication
  - **reconfigurability (potential)**
    - processors (SW), reconfigurable HW, parametrizable ASICs
- **Digital radio**
  - **SW signal processing IPs**
  - **reconfigurable HW signal processing IPs**
- **SW architecture for reconfiguration**

System design methodology for heterogeneous platforms

IP design methodology

Platform/application abstraction

Reconfiguration management

HW generic platform

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HW generic platform requirements

- **Genericity**
  - many different applications are possible
- **Heterogeneity**
  - processors, reconfigurable HW, parameterizable ASICs
- **Modularity**
  - many daughter HW modules available, connectivity to outside world
- **Scalability**
  - third party boards may be added in the same rack
- **Reconfigurability**
  - thanks to processors, reconfigurable HW, parametrizable ASICs
- **Portability**
  - C language whatever processor, VHDL for reconfigurable HW
- **SW co-design tools**
  - automatic optimized mapping and code generation, HW/SW abstraction

HW generic platform

- **multi-fixed point DSP mother-board**
  - 4 TI C6203 DSPs @300 MHz
  - high speed bi-FIFO comm links
  - host - target ethernet link (100 Mb/s)
  - supporting 2 daughter modules
- **2 channel wideband Tx module**
  - upconverter (DUC), D/A converter in IF
  - upconverter is bypassable
  - programmable parameters
- **2 channel wideband Rx module**
  - A/D converter in IF, downconverter (DDC)
  - downconverter is bypassable
  - programmable parameters
- **2 FPGA XC2V3000 Xilinx module**

possible digital IF

possible computing heterogeneity (DSP + FPGA + digital & analog param. ASIC)

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Digital radio

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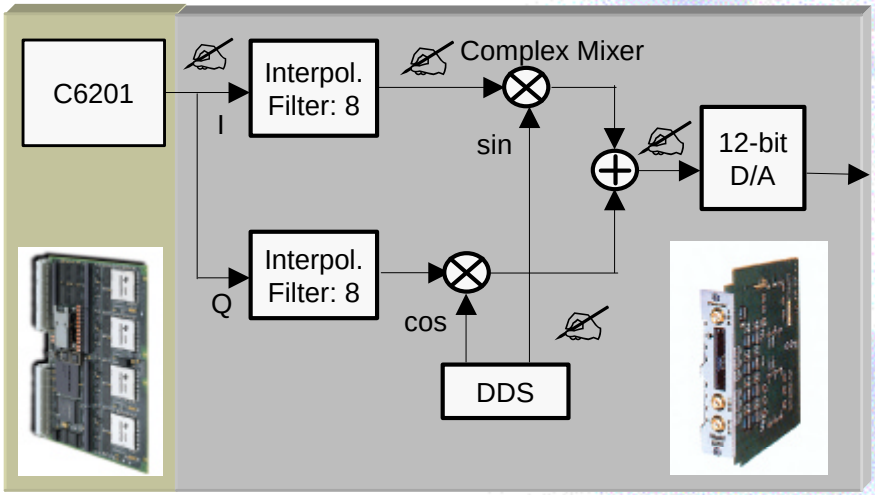
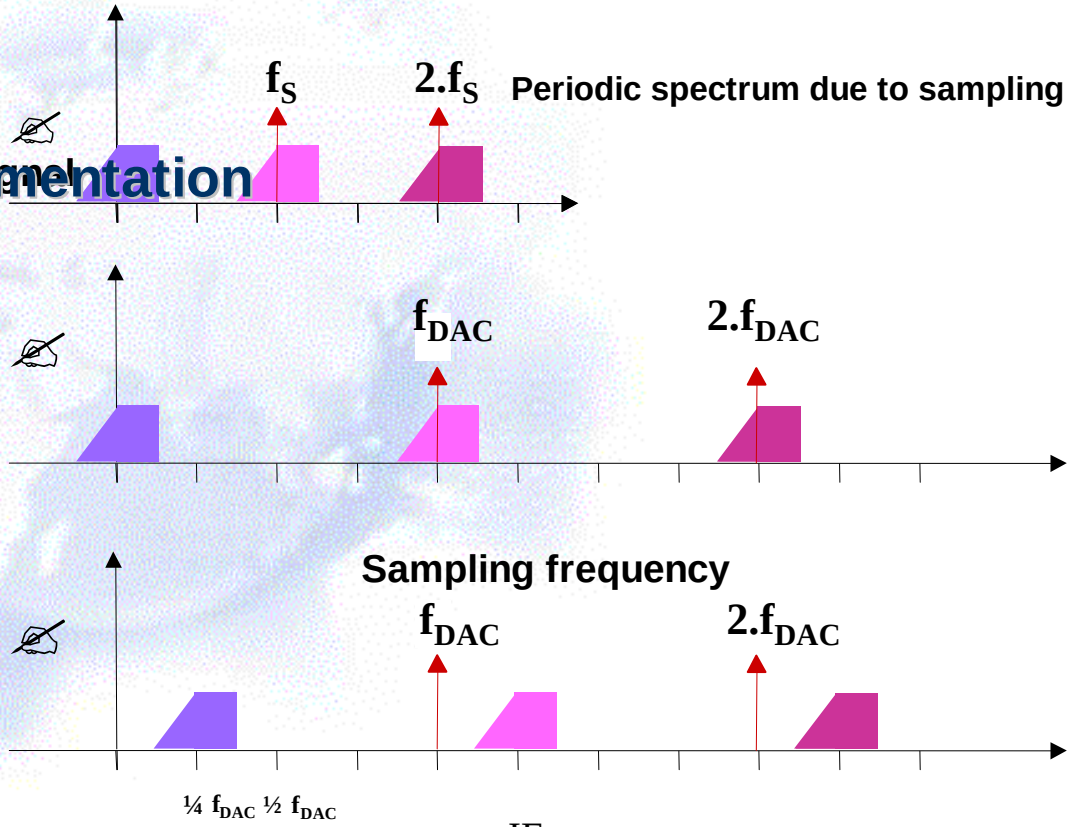
"Undersampling" - Tx

- **Objective:**

digital radio efficient implementation



f_S f_{DAC}



A "high" frequency signal is generated with a low computing rate

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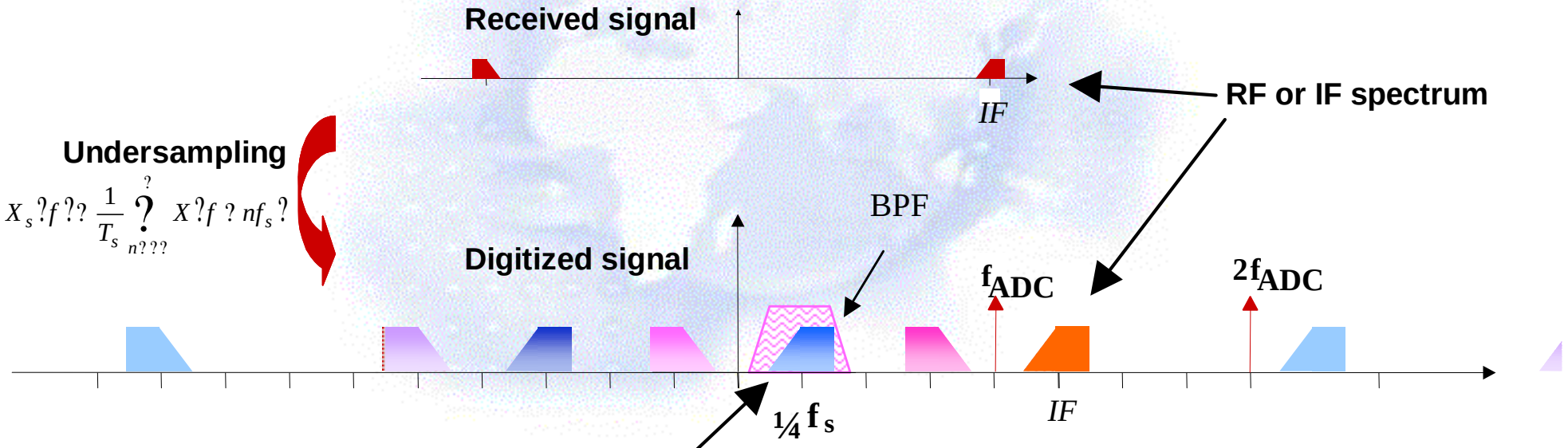
Undersampling - Rx

Undersampling

low needs in processing power by reducing sample rate

$f_S < 2\ f_{max}$ $f_S > 2\ B$ $f_S = 4\ IF/5$



$X_s(f) = \frac{1}{T_s}$ [$X(f - 3f_s)$ | $X(f - 2f_s)$ | $X(f - f_s)$ | $X(f)$ | $X(f + f_s)$ | $X(f + 2f_s)$ | $X(f + 3f_s)$]

Signal that will be effectively demodulated (low computing rate)

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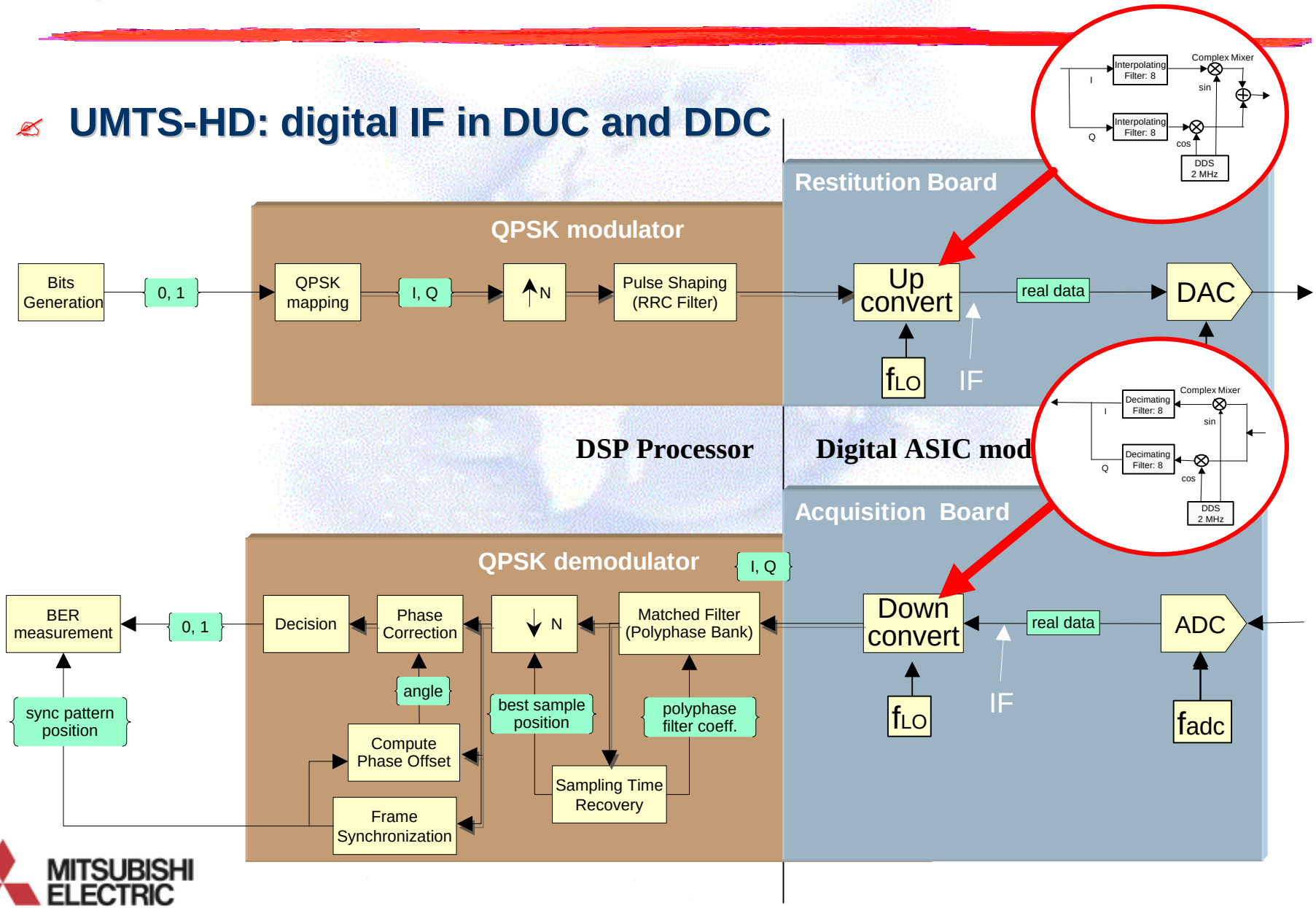
Digital IF - 3G UMTS FDD example

UMTS-HD: digital IF in DUC and DDC



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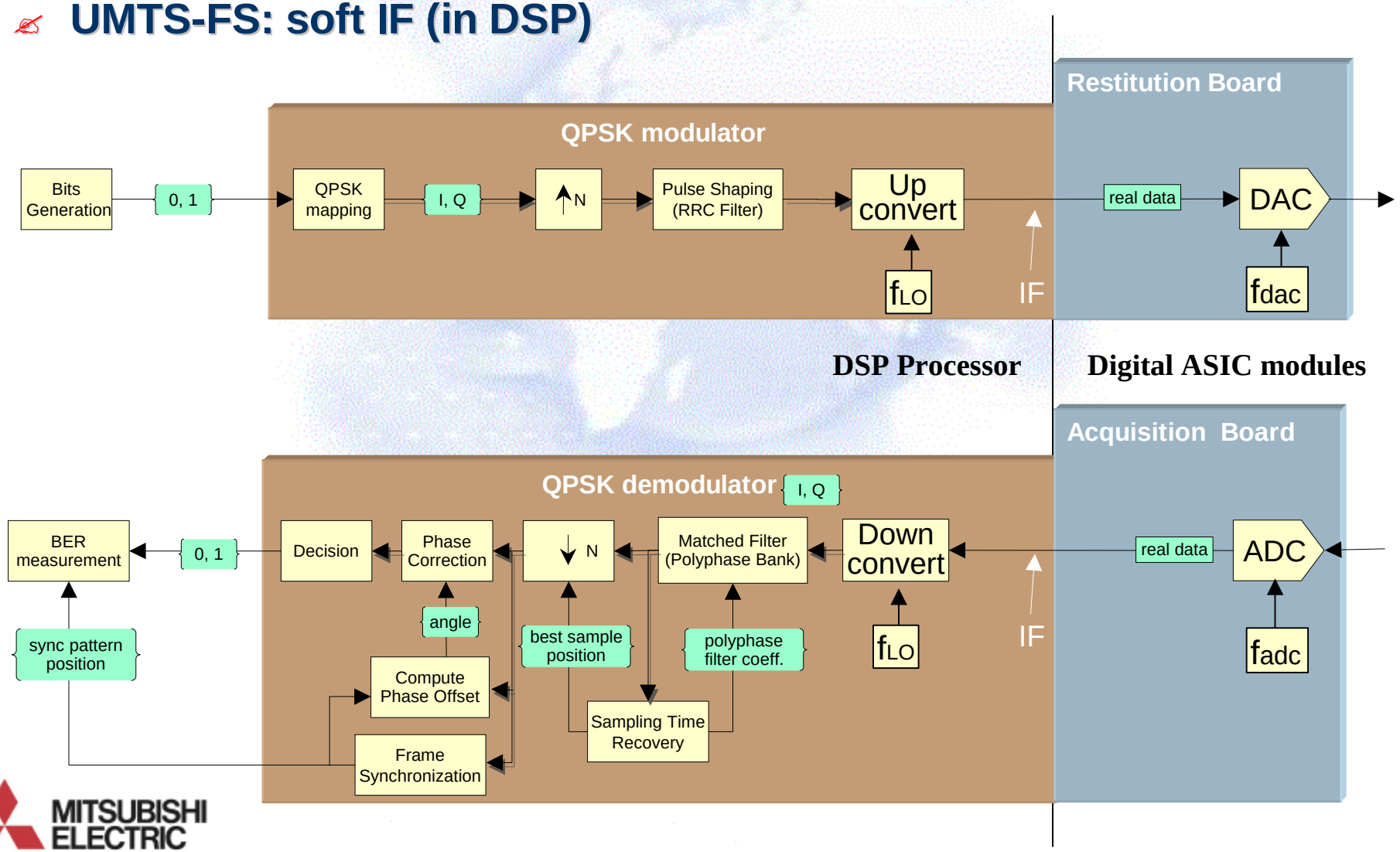
Digital IF - 3G UMTS FDD example

UMTS-FS: soft IF (in DSP)



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Digital radio

Performance evaluation for a variety of transceivers*

	UMTS FDD	GSM/DCS	EDGE	BlueTooth
Symbol rate	3840	270.833	270.833	1000
Hop duration				1 ? s
Modulation				FH-CDMA
Frequency hopping				625 ? s 1600 hops/s
Modulation				GFSK h: 0.28 - 0.35
Pulse shaping				Gaussian BT: 0.5
data rate (kbits/s)	144-2000	9.6-13	< 384	1000

Modem	Req. Perf. ksym/s	Tx Modulator		Rx Demodulator	
		C6201 200MHz	C64x 1GHz	C6201 200MHz	C64x 1GHz
UMTS-HD	3840	960.8	4804	879.1	4395.5
UMTS-FS	3840	1434.2	7172	1435.3	7176.5
GSM	270.83	444.6	2223	753.56	3767.8
EDGE	270.83	1036	5180	506.73	2533.65
Bluetooth	1000	444.6	2223	825.49	4127.45

* Rx: matched filtering, sampling-carrier-symbol synchro, M-ary decoding
Tx: M-ary coding, pulse shaping
** Plus software IF for UMTS-FS

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SW architecture for reconfiguration

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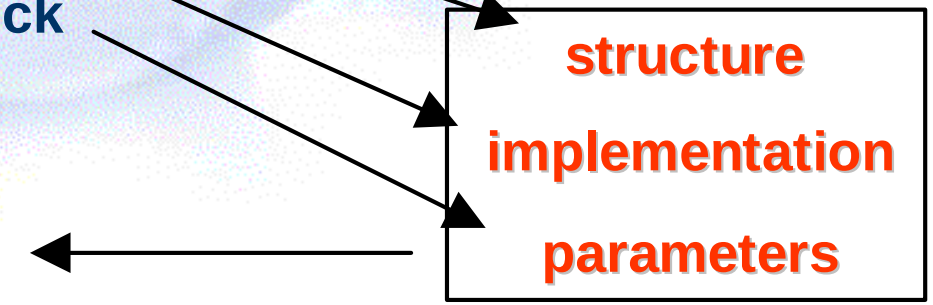
SW architecture for reconfiguration

- **Component-based approach**
  - "SW reconfigurable component" on a processor
  - "HW re-configurable component" on a FPGA or parameterizable ASIC
- **A system is made of signal processing components with**
  - **their interconnections map**
  - **the behavior of each block**
  - **the parameters of each block**



- **A reconfiguration is made through a configuration message containing all the configuration information of the blocks that are reconfigured**

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Configuration information exchange

- **Configuration message**

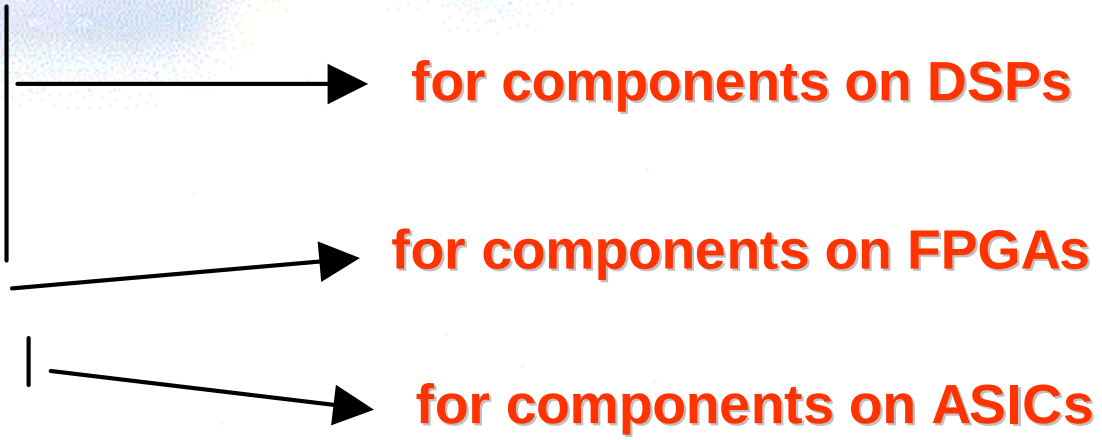
Config_ID	Config_DATA

- **Configuration ID**
  - logical reference to the configuration DATA
  - will be transformed to a physical reference by the configuration manager CMan
- **Configuration DATA**

HW parameters	SW parameters	SW functions	HW functions	IO connections
scalar values	*scalar values*	*binary code*	*binary bitstream*	*pointer tables*

may contain

- SW code for run
- SW code for init
- SW parameters
- IO connections
- HW bitstream
- HW parameters



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Reconfigurable components

- **Reconfigurable functional blocks**
  - I/O interface
  - parameters
  - implementation
    - *init()*, *run()*
  - invariant function
    - *reconfigure()*
- **Reconfiguration: *reconfigure*()**
  - **called by the configuration manager CMan**
  - **steps**
    - subset of configuration data is passed
      - new code or bitstream
      - new parameters
      - new I/O
    - function pointers for *init*, *run* are set to the desired implementations with the adequate parameters and connections
    - *init* is called to setup internal state (optional)
    - *run*

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Reconfiguration process

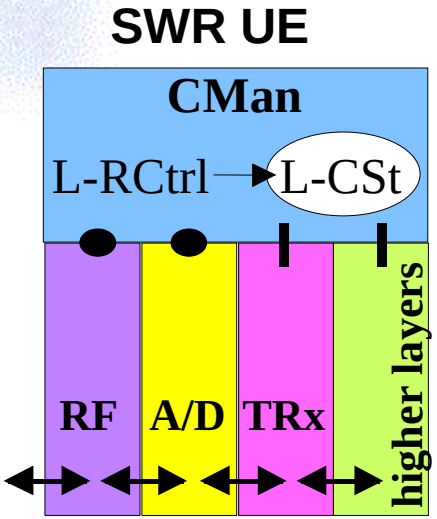
- **3 steps approach**
  - **download (may be skipped)**
  - **install**
  - **activate**
- **Download**
  - if the reconfigurable system does not already have in memory the appropriate configuration
- **Installed configuration**
  - stored in execution space but not diffused
- **Active configuration**
  - stored in execution space
  - parameter values have been diffused and code references have been resolved in the functional blocks

Configuration cache

- **1st level - configuration present in execution memory (L-CSt1)**
  - installed and ready for execution (after some init sometimes)
  - reconfigure = software switching from one to another
- **2nd level - configuration stored in the local global memory (L-CSt2)**
  - first bring configuration into execution memory (1st level cache)
  - update configuration availability tables
  - reconfigure (software switch)
- **3rd level - configuration stored in remote (network) site (R-CSt)**
  - download configuration into 2nd level cache
  - install locally (1st level cache) & update configuration availability tables
  - reconfigure (software switch)
- **does not systematically erase other present configurations**
  - several locations may be reserved in each cache for the same component

Example of a SWR User Equipment

- **Reconfigurable system - 3 main entities**
  - **TRx: Transceiver**
  - **CMan: Configuration Manager**
  - **L-CSt: Local Configuration Store**
    - contains the different configurations of all reconfigurable blocks
- **CMan**
  - **interfaces with all reconfigurable sub-parts of the system**
  - **L-RCtrl: local reconfiguration controller**
    - activates *reconfigure()*
    - manages the requests from the Network
      - monitoring requests from the network
      - configuration information to the network
    - consult the L-CSt
      R-CSt



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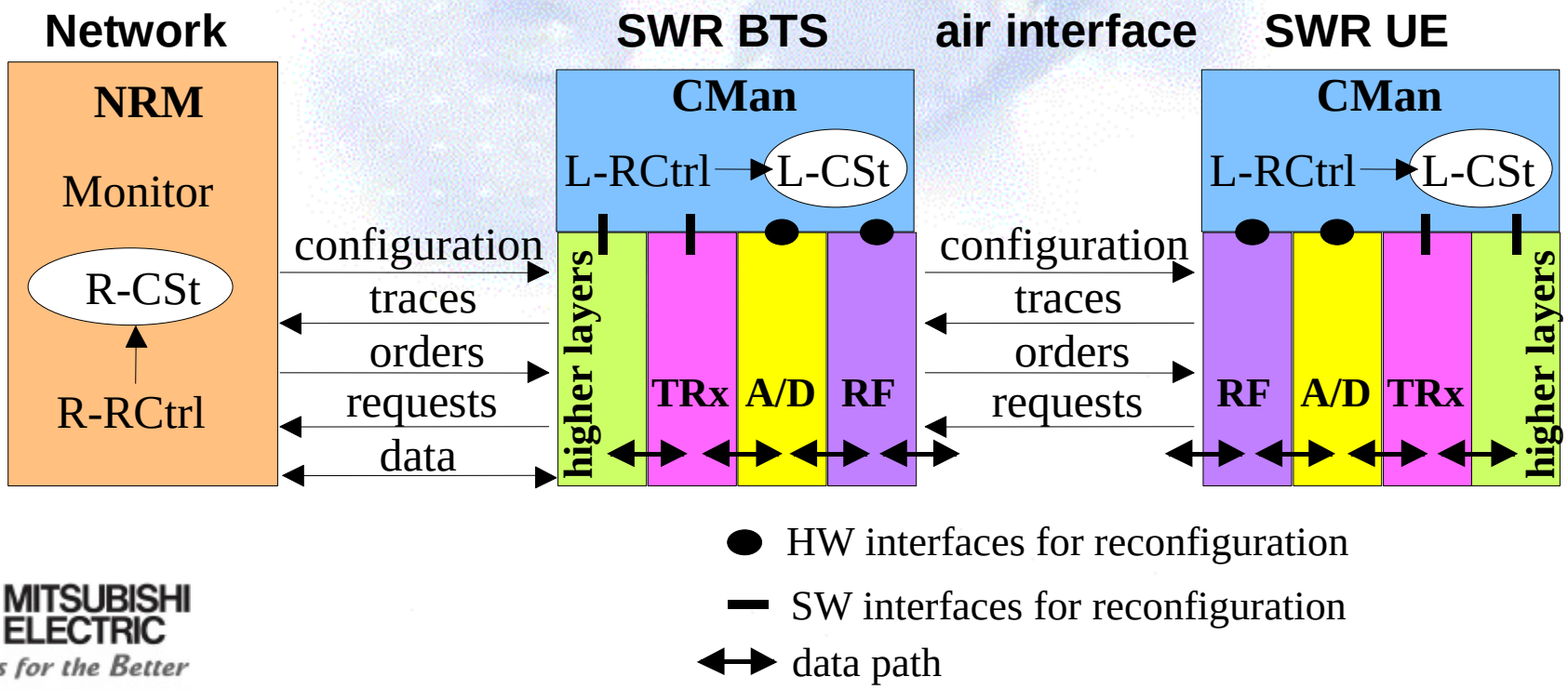
Network reconfiguration manager - NRM

- **NRM manages reconfiguration**
  - **operate monitoring tasks**
  - **consult R-CSt: Configuration Store**
  - **R-RCtrl: remote reconfiguration controller**
    - initiates reconfiguration operation



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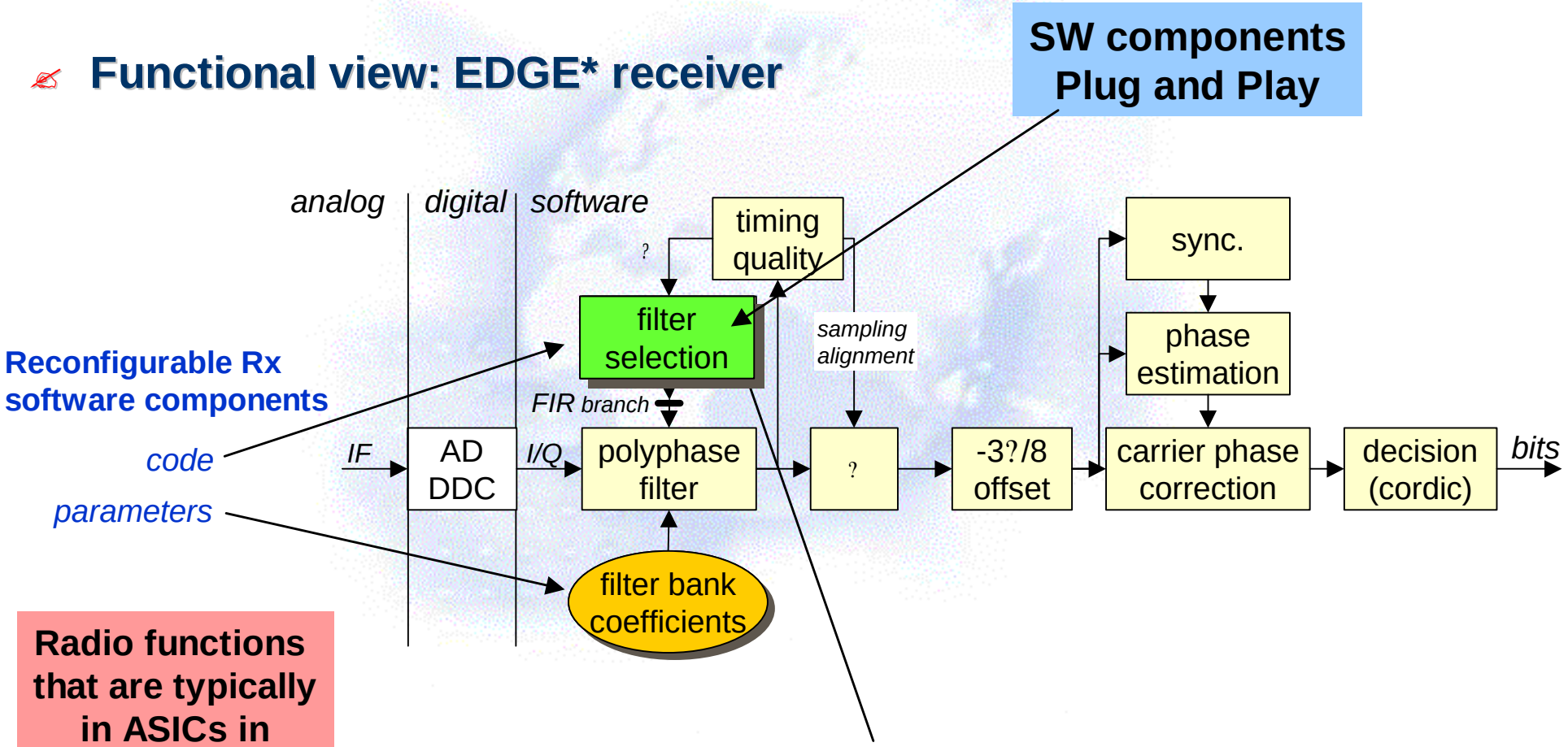
Radio application SW design

Functional view: EDGE* receiver



*EDGE (2.5G): Enhanced Data rates for GSM Evolution

Case study: dynamic reconfiguration

- **SW architecture appropriate for**
  - **heterogeneous systems**
    - processors
    - FPGAs
    - parameterizable ASICs
  - **any functionality**
    - physical layer
    - higher layers
- **tested at the moment**
  - **on multi-DSP architecture**
  - **on physical layer algorithms**
  - **without structural changes**
  - **code and/or parameter download**

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Demonstration film

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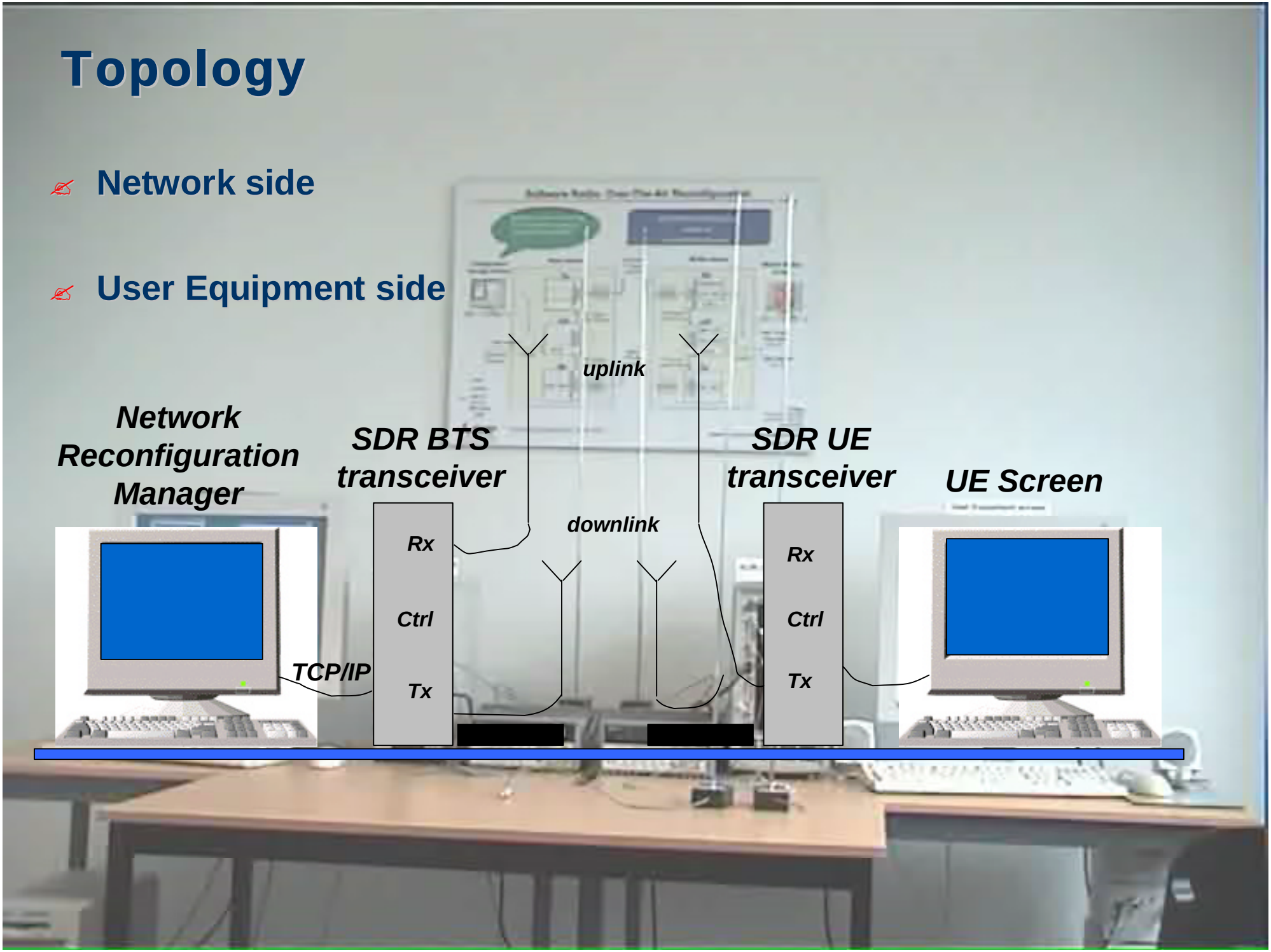
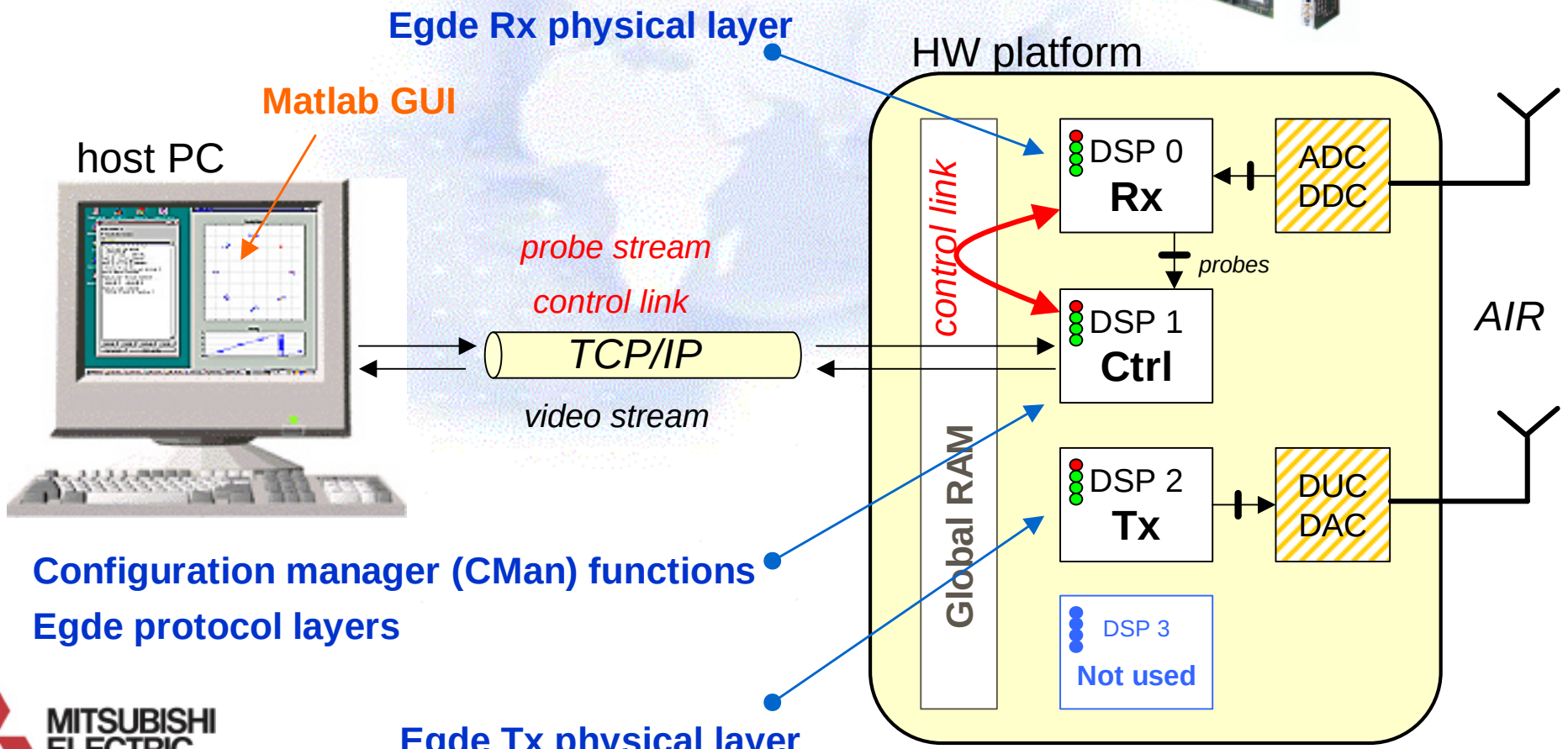
Topology

- Network side
- User Equipment side



Case study: dynamic reconfiguration

- Mapping of the radio application on the HW
  - including control



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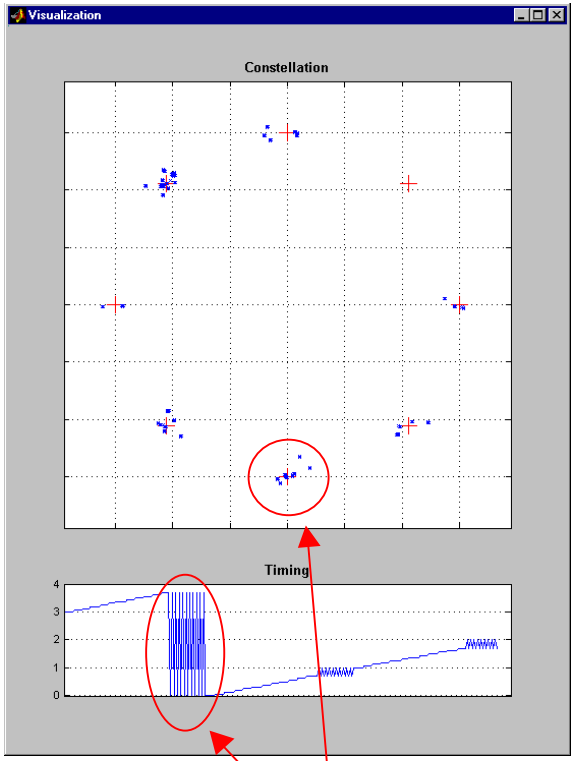
NRM GUI for reconfiguration management

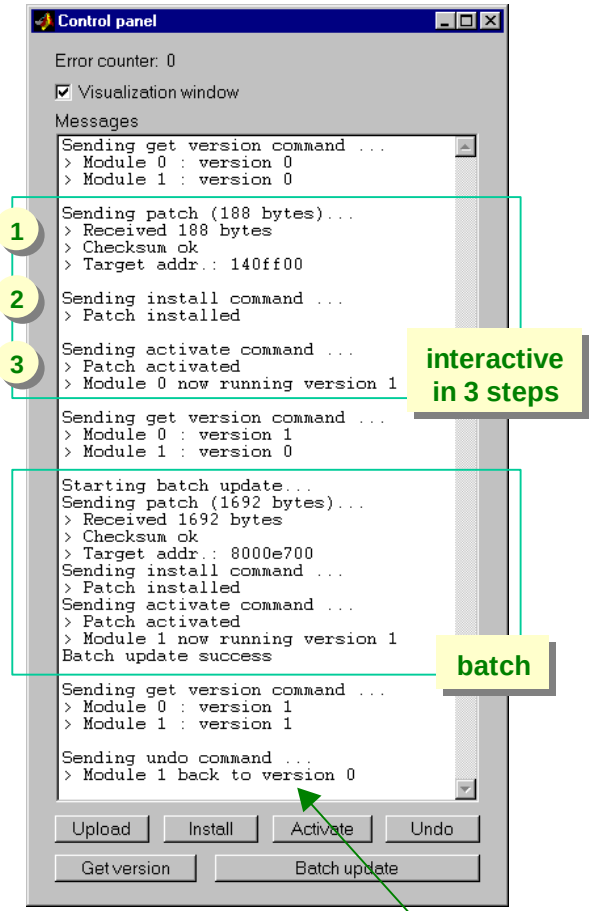
reconfiguration manager

monitoring tool



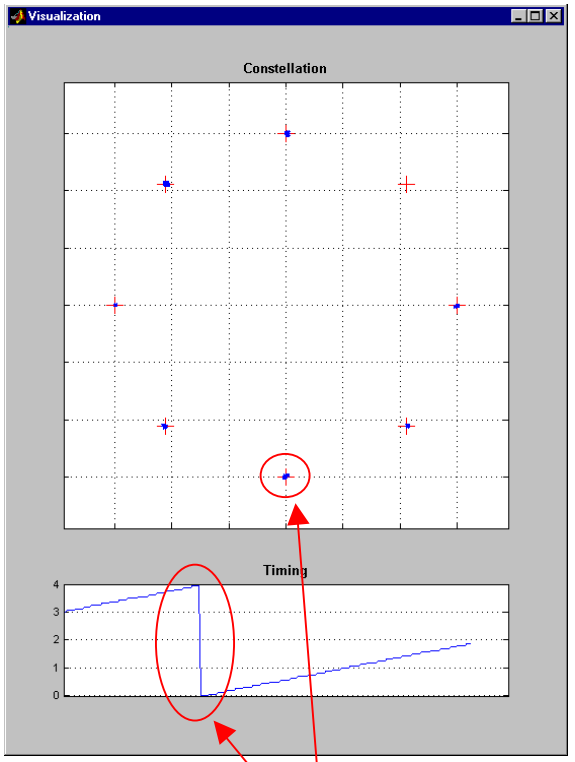
no noise
sampling clock freq. drift

Bug in the Timing Recovery sub-system



rollback

monitoring tool



Bug corrected by selective code change, i.e. Module 0

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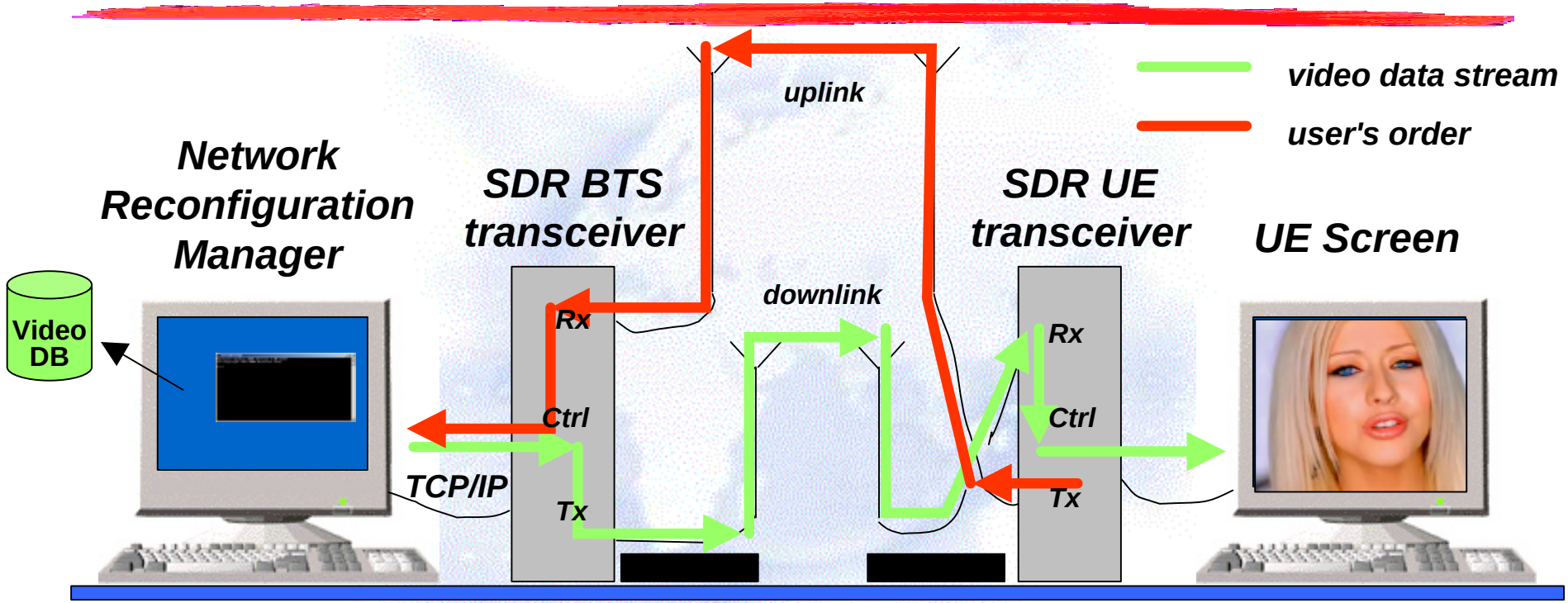
Video application



Video service order of the user

1 - the network has a video database

2 - launch a video server

3 - send the video stream to the BTS

4 - conversion of the stream to the reconfigurable EDGE protocol stack

5 - EDGE Tx

6 - EDGE Rx

7 - identification of the service

8 - video stream is displayed on the screen

TCP/IP over the air

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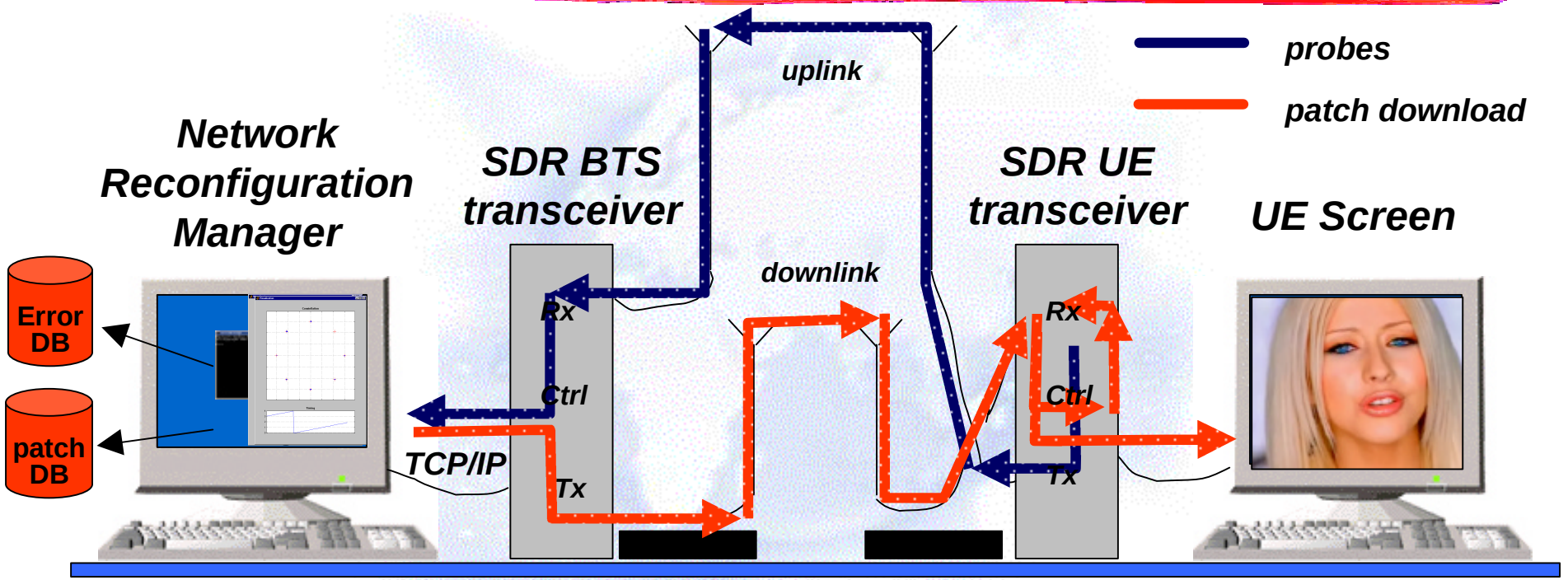
Reconfiguration at run-time: patch download



Network reconfiguration manager

1 - monitors a SDR UE

2 - detects some dysfunction

3 - identifies the problem

4 - finds the corresponding patch in its patch database

5 - download the patch to the UE ircumstances included in the data stream ew processing

6 - separate video from reconfiguration data

7 - install reconfiguration data in the UE's Rx internal memory

8 - activate the patch

9 - possibly: undo the operation if any problem

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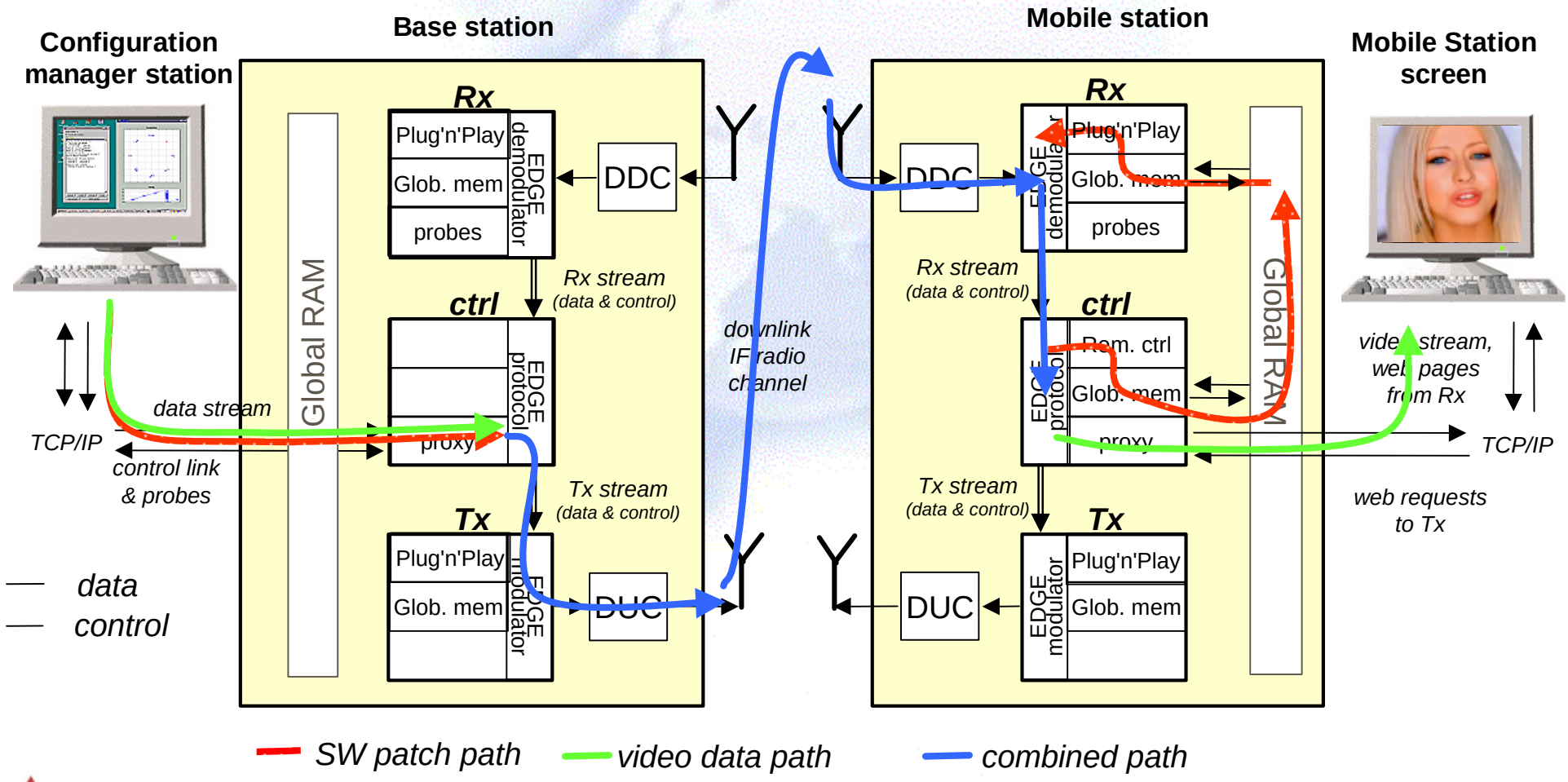
SW Patch path



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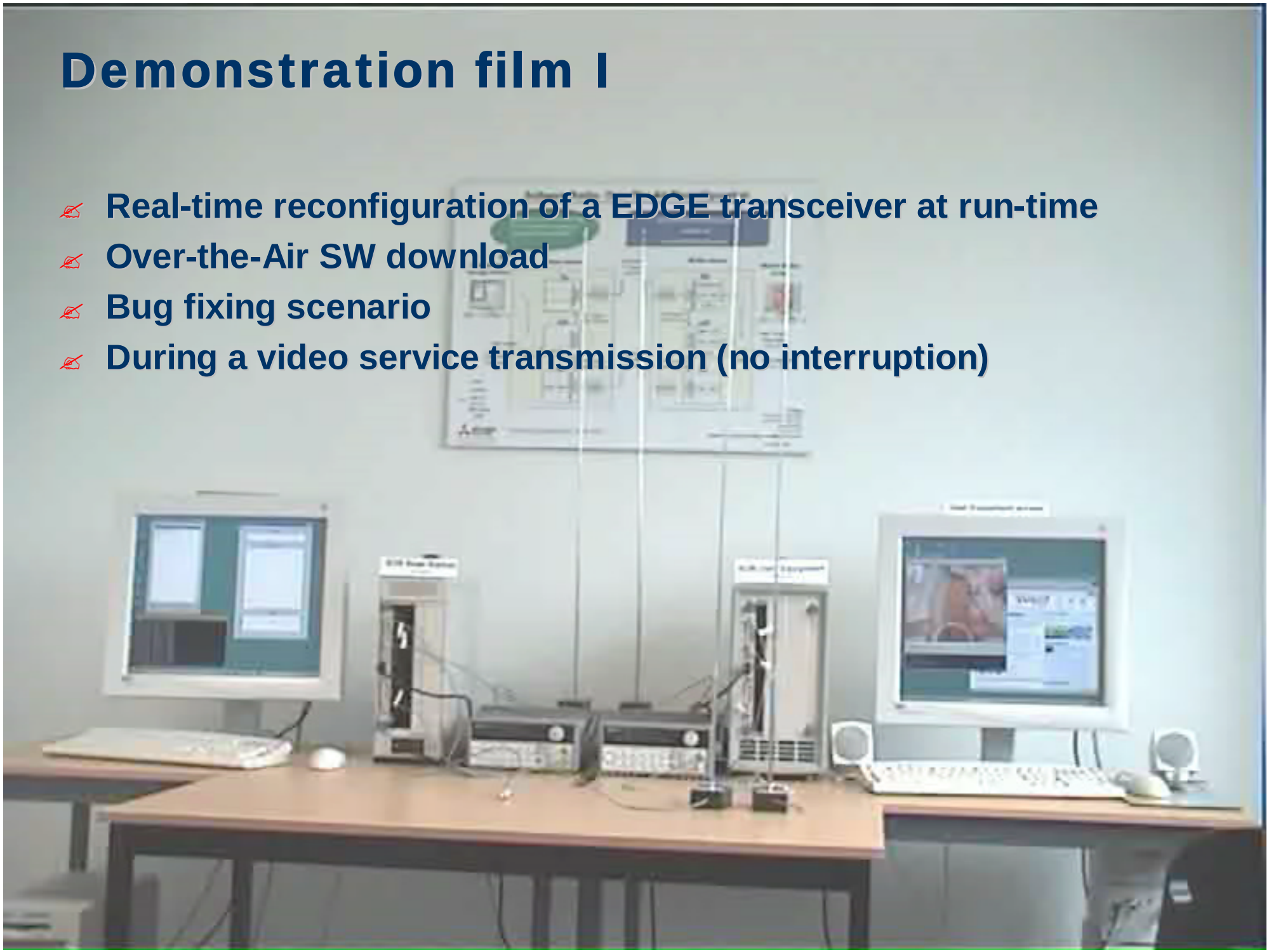
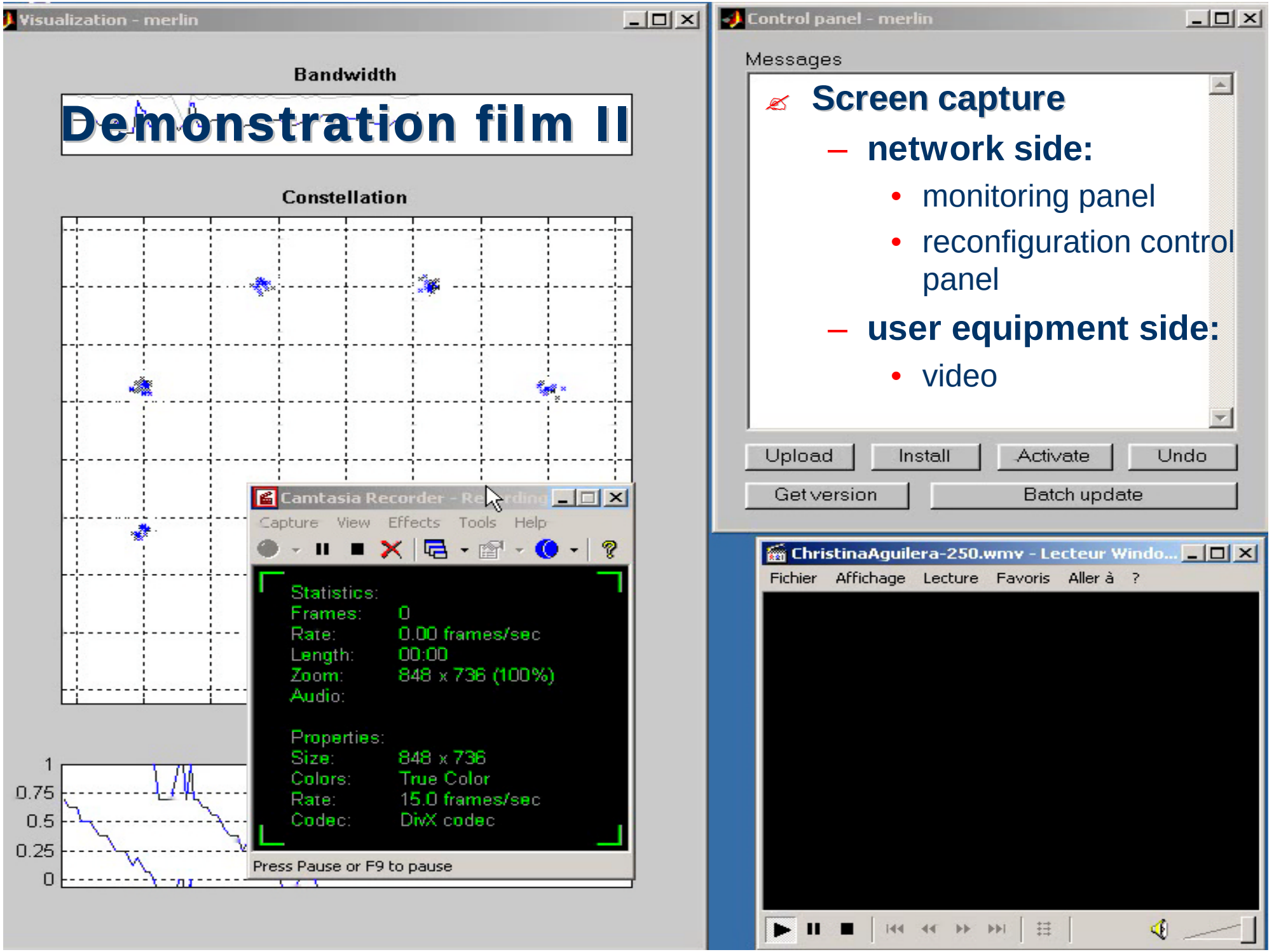
Demonstration film I

- Real-time reconfiguration of a EDGE transceiver at run-time
- Over-the-Air SW download
- Bug fixing scenario
- During a video service transmission (no interruption)




Visualization - merlin
Bandwidth
Demonstration film II
Constellation
Camtasia Recorder - Recording
Capture View Effects Tools Help
Statistics:
Frames: 0
Rate: 0.00 frames/sec
Length: 00:00
Zoom: 848 x 736 (100%)
Audio:
Properties:
Size: 848 x 736
Colors: True Color
Rate: 15.0 frames/sec
Codec: DivX codec
Press Pause or F9 to pause
1
0.75
0.5
0.25
0
Control panel - merlin
Messages
Screen capture
– network side:
• monitoring panel
• reconfiguration control panel
– user equipment side:
• video
Upload
Install
Activate
Undo
Get version
Batch update
ChristinaAguilera-250.wmv - Lecteur Windo...
Fichier Affichage Lecture Favoris Aller à ?

Real-time

- **only modules of potential interest are designed to be reconfigurable**
  - impact on a usual design may be very light
  - very low memory overhead necessary
  - permits a step by step deployment
- **3 steps download operation**
  - 3 cache levels
  - using DMA capabilities
- **small-size patch**
  - less than 0.5% of the overall code size
    - 4 kbits for the sampling time adjustment algorithm, 13 kbits for filter coef.
  - less than 0.5% of the processor cycles are needed
  - download + install < 50 ms (priority to signal processing)
- **keep former version in memory**
  - no need to download to come back to former version
    - if conditions are coming back to previous ones

Roadmap

- Mitsubishi Electric Telecom
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Business cases for dynamic reconfig.

- Manufacturer
  - bug fixing
  - upgrade capabilities
- Service provider
  - bug fixing
  - performance enhancement
  - cell capacity optimization (transmit power adaptation)
- User may benefit in a transparent manner from
  - battery optimization
  - real-time quality of service management

- needs for standardization and regulation

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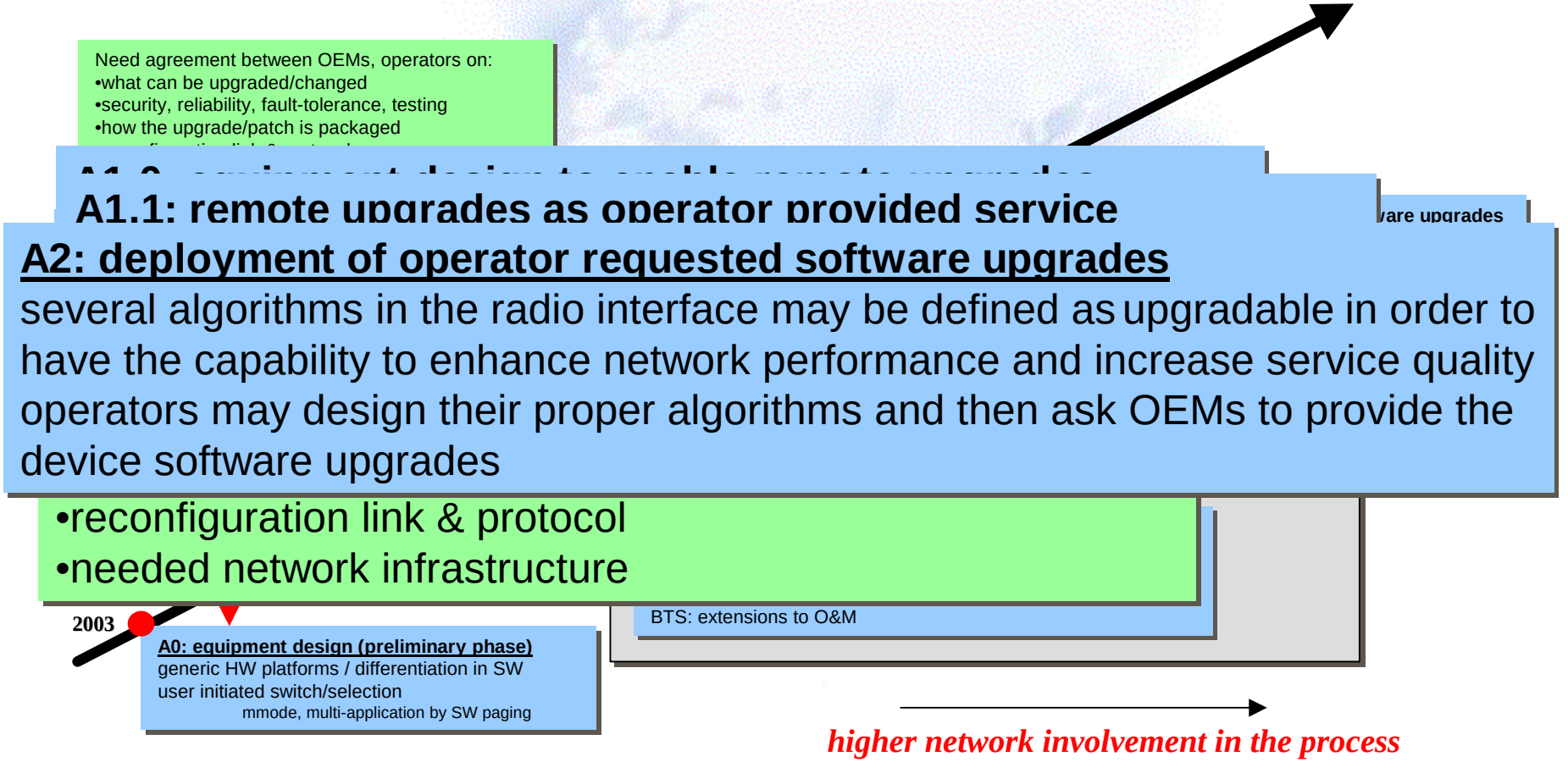
Technical feasibility roadmap (I)

Reconfiguration for remote software upgrades



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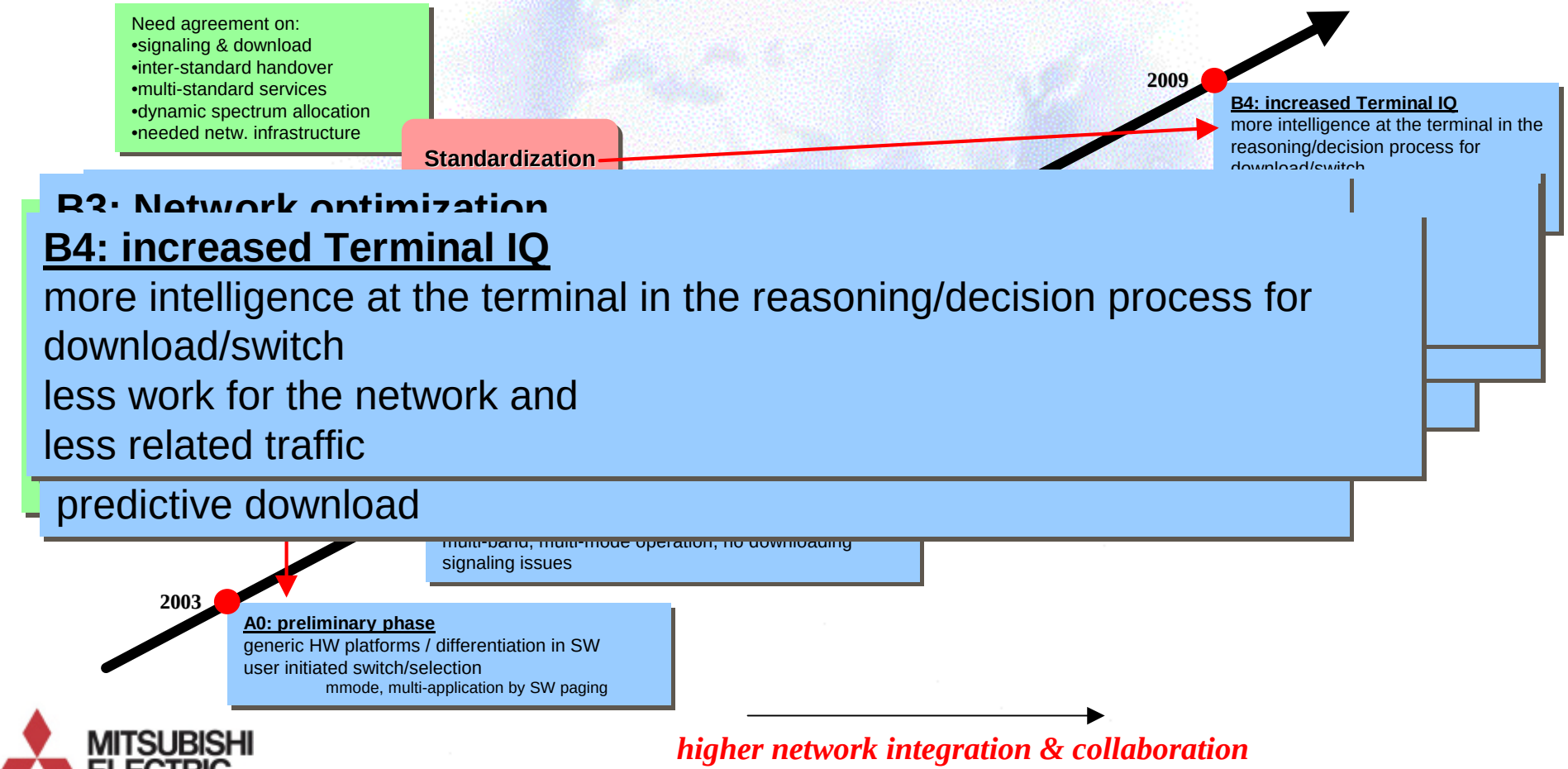
Technical feasibility roadmap (II)

Reconfiguration for network integration & optimization



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Perspectives

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Perspectives I

- **Conceptual level**
  - **Structural changes**
    - structural representation has to be enhanced
    - functions to operate changes in the structure
  - **Scenario description language**
    - to deal with more complex reconfiguration procedures
    - automatic reconfiguration procedure deduced from changes nature
- **Reconfigurable HW (FPGA)**
    - reconfigure blocks located in FPGAs
    - partial reconfiguration
- **Imply reconfiguration aspects in a high-level HW/SW co-design methodology**
    - automatically generate the different configurations
    - automatically generate the reconfiguration procedure

Perspectives II

- **More complex reconfiguration scenarios**
  - **algorithm with initialization phase**
    - former and new algo. run together until new algo converges
    - then switch
  - **multi-mode, multi-standard**
    - with download or not
- **Reliability**
  - **local initiative**
    - UNDO initiated by the CMan after a timeout
  - **remote initiative**
    - some intelligence in the NRM manages the remote UNDO

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E²R: End-to-End Reconfigurability in EU

- **IP project submitted to the European 6th Framework Program**
- **Work packages**
  - **WP1: System Research**
    - technical, business and regulatory global approach across all WPs
  - **WP2: Equipment Management**
    - reconfiguration capabilities of equipments (terminal and BTS)
  - **WP3: Network Support for Reconfiguration**
    - network management for reconfiguring terminals and network entities
  - **WP4: Radio Modem Reconfigurability**
    - local configuration control and mechanisms for reliable reconfiguration
  - **WP5: Evolution of Radio Resource and Spectrum Management**
    - cognitive radio, network-oriented perspectives, spectrum control
  - **WP6: E²R Proof of Concept Evolutionary Environment**
    - demonstrator
- **Some of the partners:**

Motorola, Siemens, Thales, Nokia, Mitsubishi, Panasonic, Alcatel, NTT DoCoMo, Telefonica, FTR&D, UoAthens, UoSurrey, King's College...

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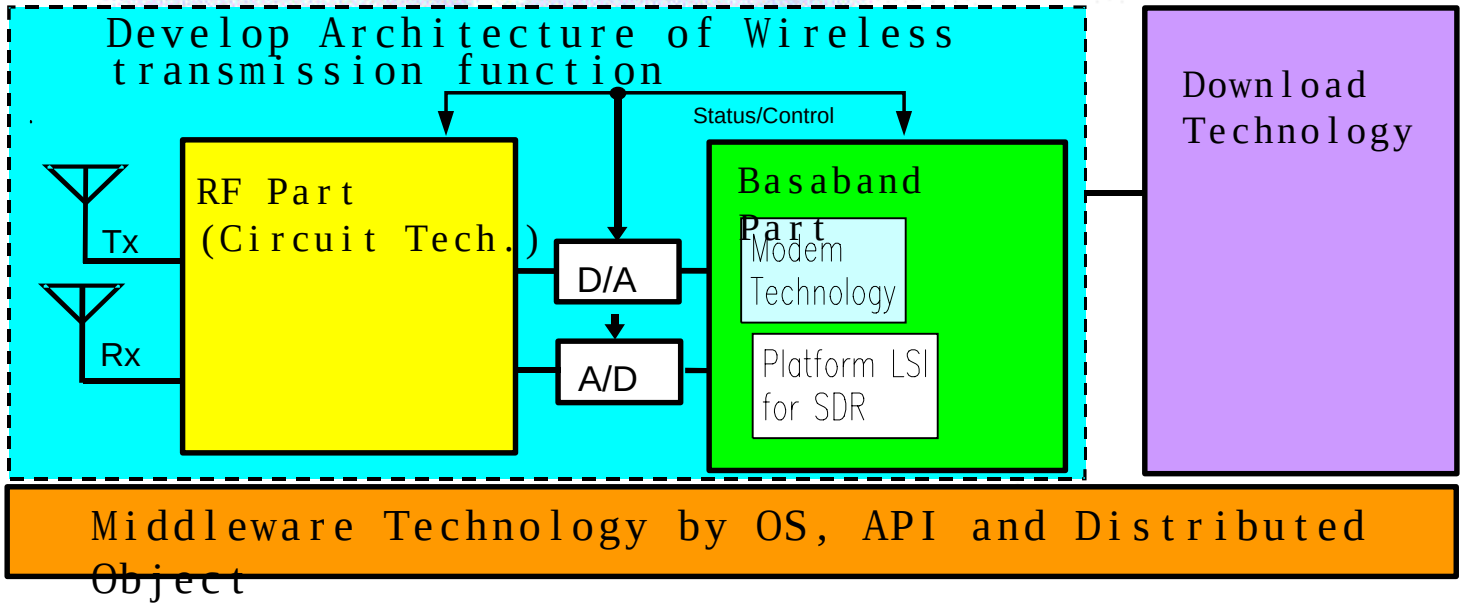
TAO-SDR in Japan

- **Japan National Project**
  - **Mitsubishi Electric Japanese Lab (leader), Toshiba, Fujitsu**
  - **4 years project (02 to 05)**
- **Objectives**
  - **R&D realization of 4G terminals with key SDR technologies**
    - system architecture and devices for multi-mode/multi-band SDR terminal which supports 100Mb/s transmission rate and realizes seamless connection for multiple wireless systems



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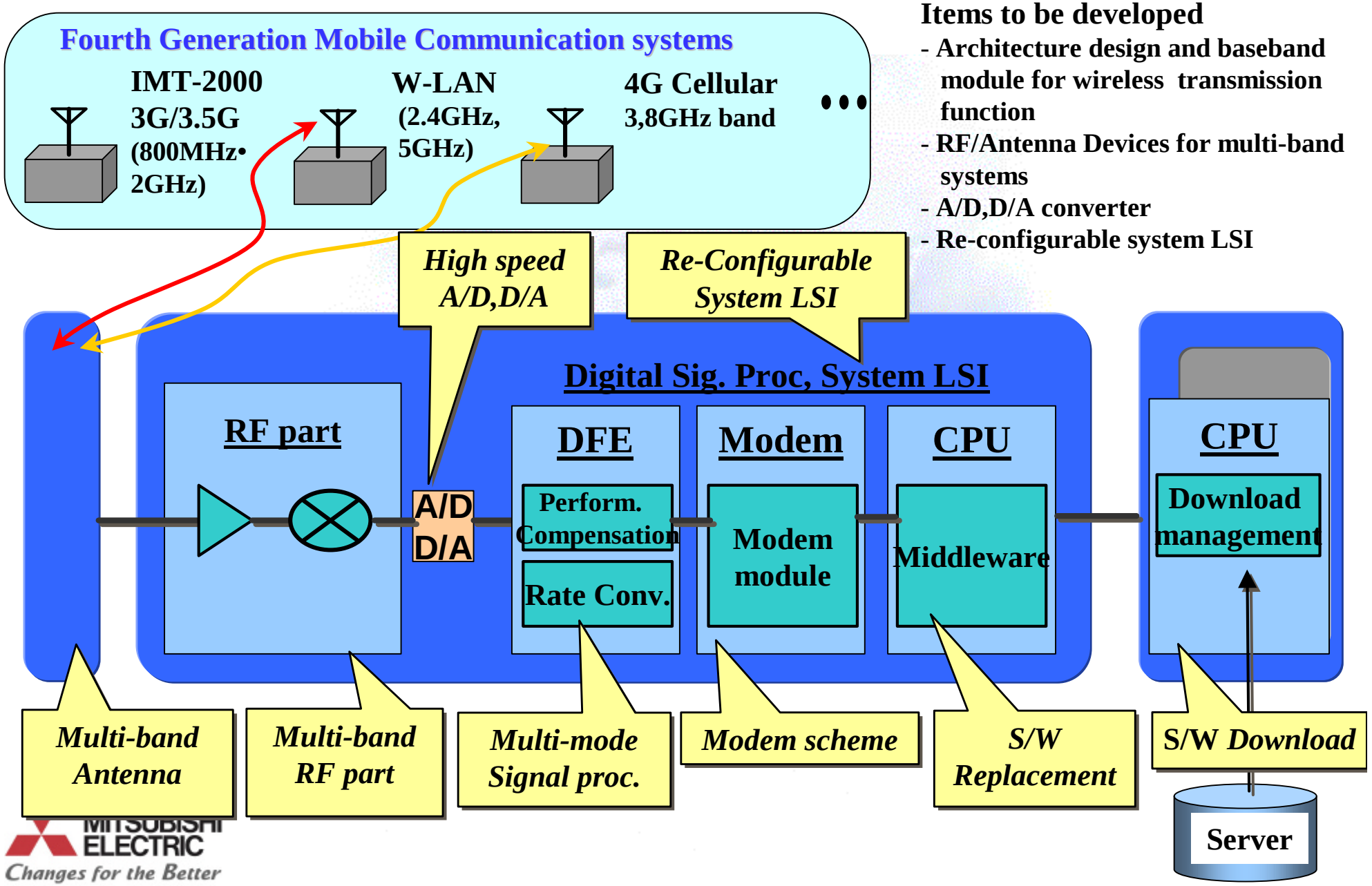

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Conclusion: keywords

- Dynamic reconfiguration of a radio algorithm
- Over-the-air SW download
- Bug fixing
- Performance enhancement
- At run-time of an application
- Code and/or parameter download
- SW architecture
  - component-based
  - plug and play
- Laboratory demonstration

- Standardization and regulation effort are needed

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Conclusion

- **SDR Forum market survey by Gartner Consulting (jan. 2002)**
  - **for both US and EU wireless operators:**
    - "SDR technology will have a great benefit in fixing bugs in handset"
    - "rapid SW bug fixing is expected to be a key value proposition for the handset market, especially as 3G emerges"
    - "bug fixing is the clear top choice driven by the need to smooth the introduction of 2.5/3G services"
- **Operators will soon require dynamic reconfiguration for bug fixing**

- **Orange introduced in Oct. 2002 an Over-The-Air phone settings configuration (through SMS): "MyPhoneSettings" (from Swapcom)**
  - 20.000 profiles are downloaded every day
  - Orange customer service that answers parameter settings issues saves 180.000 Euros each month

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