Real-Time Communications: from Fieldbuses and Industrial Automation to Wireless and Vehicular Applications

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Real-Time Communications

- Real-Time Communications for Industrial Automation.
  - A tour on fieldbuses
  - CAN, CAN-based protocols and dynamic environments
  - The Flexible Time-Triggered Protocol
  - Ethernet as a Fieldbus
- Wireless communications: potentials and evolutions
  - Standards in the ISM band: coping with openness.
  - Supporting Real-Time Communications on wireless.
  - Vehicular communications – standards, applications and potentials
- Conclusions

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R-T Comm: Role in Control & Autom.

- The communications infrastructure must be able to support the requirements of control & automation applications.
- Periodic traffic:
  - Real Time characteristics – deadlines must be met.
  - Network induced jitter and delay - important issues.
- Sporadic traffic:
  - Also Real Time, e.g. for alarm situations.
  - Best effort for maintenance, download, upload, …
- Networked control systems
- Other approaches (QoS, …)

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R-T Communications: Fieldbuses

- "Definition" by IEC61158:
  - "A digital, serial, multi-drop, data bus for communication with industrial control and communication devices such as – but not limited to – transducers, actuators and local controllers".
- Description by Fieldbus Foundation:
  - "a digital, two-way, multi-drop communication link among intelligent measurement and control devices. It serves as a Local Area Network (LAN) for advanced process control, remote input/output and high speed factory automation applications".

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Fieldbuses

Hart TTP Unitelway ISO 8802.5
Ethernet Profibus-PA SNMP
WorldFIP Batibus
IEC 61158 CiA
P-NET SDS ICCP
Sercos BacNET
CSMA-BA EHS CSMA-DCR
EiBUS FieldBus Foundation
Interbus DeviceNet
Profibus-FMS EN 50254
ControlNet CANOpen ASI M-PCCN
Profibus-DP TTP-A
DWF TCP-IP FDDI
TTP-C Modbus FIPWay
EN 50170 TASE2 IEC
CASM ISO 8802.4 WDPF
MMS ISO 8802.3 Sinec ControlFIP JBUS
PLAN
FIPIO LON CSMA-CA Seriplex Mini-MAP
TOP
CAN UCA F8000 CSMA-CD
MAP Profisafe
Bitbus ARINC UIC 556 Digital Hart
IEC 6375 CIP LocaFIP
M-Bus Sycoway GENIUS OPTOBUS
WITBUS
VAN Euridis
J1850 SwiftNet

J.P. Thomesse, Novembro de 1999

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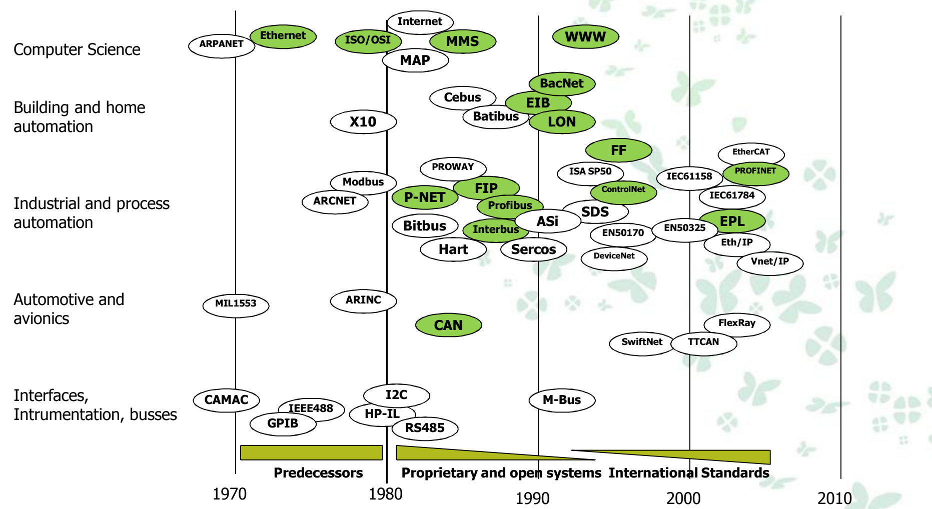
Fieldbuses and Industrial Ethernet



Adapted from Thilo Sauter, 2005

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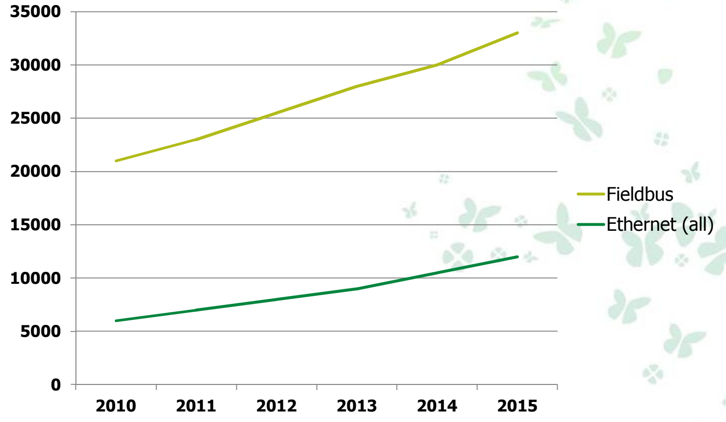
Fieldbuses:

New nodes installed worldwide (in thousands)



Source: IMSreseach, December 2011

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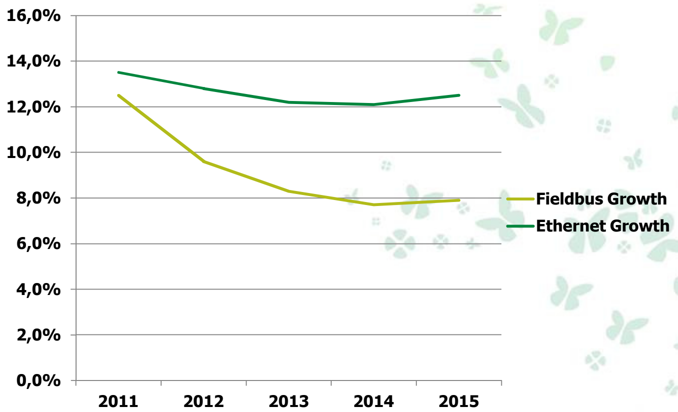
Fieldbuses:

New nodes installed worldwide (fieldbus versus Ethernet growth)



Source: IMSreseach, December 2011

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Strategies for Real-Time Communications in Safety Critical Applications

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Preserving real-time capabilities

- Real-time support in industrial networks has to be provided from the **Medium Access Control** (MAC) layer up to the application layer.
- Several possible techniques to handle a shared medium:
  - **Controlled access protocols**:
    - Centralized or distributed
  - **Uncontrolled access protocols**
    - Based on the CSMA Carrier-Sense Multiple Access protocol
    - Must be extended with additional features to improve their real-time behaviour.
- Must provide a priori **deterministic guarantees** for the timely delivery of packets between two end-points.

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Protocol Taxonomy

Controlled access		Uncontrolled access
Centralized	**Distributed**	CSMA/CD (CSMA/Collision Detection)
Master Slave	Token passing (virtual or physical)	CSMA/BA (CSMA/Collision Bitwise Arbitration)
	TDMA	CSMA/DCR (CSMA/ Deterministic Collision Resolution)
	Timed-Token	CSMA/CA (CSMA/Collision Avoidance)

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Strategies for RT communications

- Safety critical communications usually rely on fully static solutions.
  - Maximize a priori knowledge (favors certification).
  - A priori knowledge is required to distinguish correct from incorrect system states.
  - E.g. Time Triggered Protocol (Vienna 1994).
- However flexibility is a desired property:
  - To support evolving requirements.
  - To simplify maintenance and repair.
  - To improve the efficiency in using system resources.
  - i.e. to offer multiple levels of QoS management in real-time.

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Strategies for RT communications

- It was found important to provide a high degree of **operational flexibility**, specifically, **on-line adaptation** capabilities, in Real-Time communication protocols, including distributed embedded systems **without compromising dependability**,
- In (often) resource constrained applications, based on **standard communication protocols**

→ **Flexible Time-Triggered (FTT) model**

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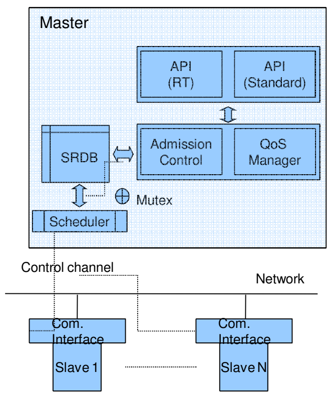
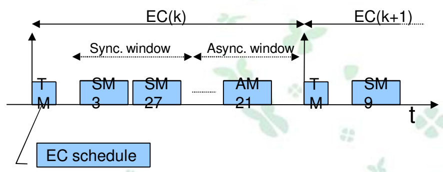
Flexible Time-Triggered Architecture

- System Architecture



Control channel



Control channel:
- Master sends a periodic Trigger Message (TM), creating regular Elementary Cycles (EC), and containing the EC schedule

Data Network:
- Slaves transmit according with the TM

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FTT Generic Properties

- Master/multi-slave scheme for reduced overhead
  - Single TM triggers several slave messages
- TM may trigger message transmissions as well as tasks
  - Holistic scheduling supported
- Scheduling policy independent of the underlying bus protocol
  - Arbitrary scheduling policies can be implemented
- Support to different traffic types:
  - Synchronous (TT), controlled autonomously by the network
  - Asynchronous (ET), triggered explicitly by the application
  - Real-time: subject to admission control; reserved resources
  - Non real-time: tx. in background wrt RT traffic; best effort

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FTT on top CAN

- CAN – Controller Area Network.
- CAN history and timeline
  - Developed in 1984 by Bosch for automotive applications
  - Still the main bus embedded in vehicles in 2012
  - Open protocol, lots of research concerning its properties.
  - Offers the lower layers of important automation protocols:
    SDS, CANOpen in Europe
    DeviceNet in the US
  - Seminal research by Tindell in 1994/5 demonstrated the adequacy to support real-time applications.
  - Almost standard currently in many microcontrollers.
- Still lots of research going on: topologies/architectures for dependable operation, message sheduling, …

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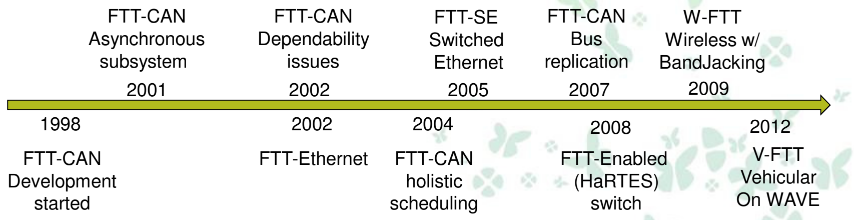
Flexible Time-Triggered Protocol

- The Flexible Time-Triggered (FTT) protocol family has been essentially developed at Aveiro, since 1998



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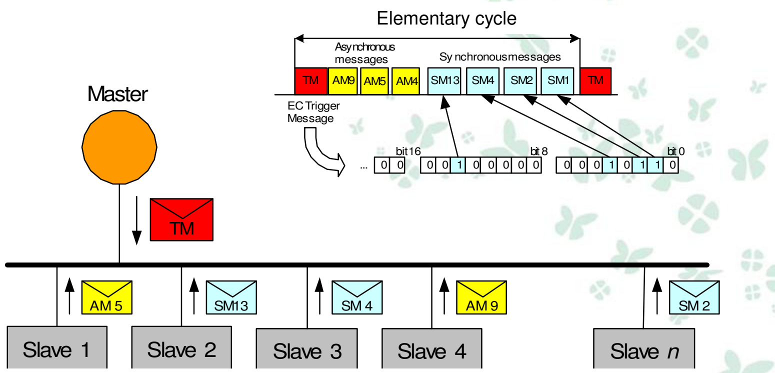
Flexible Time-Triggered (FTT-CAN)

- Uses payload of CAN (8 bytes) to transmit flags to trigger messages
- Relies on CAN native message arbitration either for the transmission of asynchronous messages or for the arbitration among synchronous messages.



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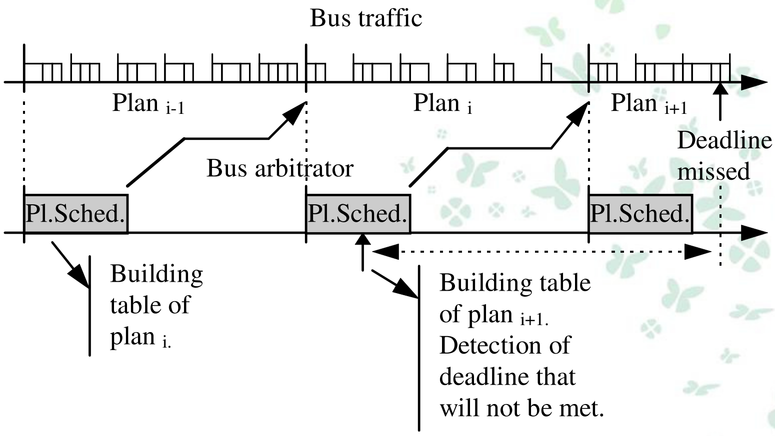
FTT-CAN Software based scheduling

- The Planning Scheduler:
  - A solution for low processing power micro controllers



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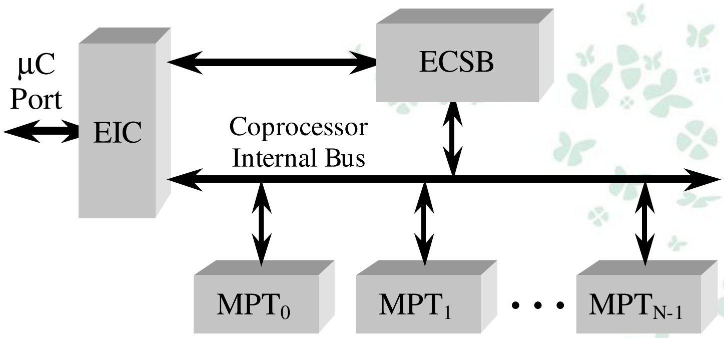
FTT-CAN Hardware based scheduling

- MESSAgE:
  - FPGA-based Coprocessor for Fieldbus Traffic Real-Time Scheduling
- Elements of the coprocessor architecture:
  - ECSB - EC-Schedule Builder; MPT - Message Production Timer;
  - EIC – External Interface Controller



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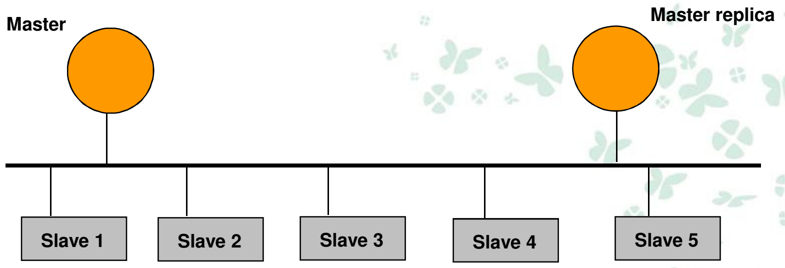
Fault Tolerance in FTT-CAN

- Master is a single point of failure, thus replication needed:
  - Synchronization protocol
  - Agreement protocol to handle consistent updates of replicated data structures
  - Master replacement and policing mechanism



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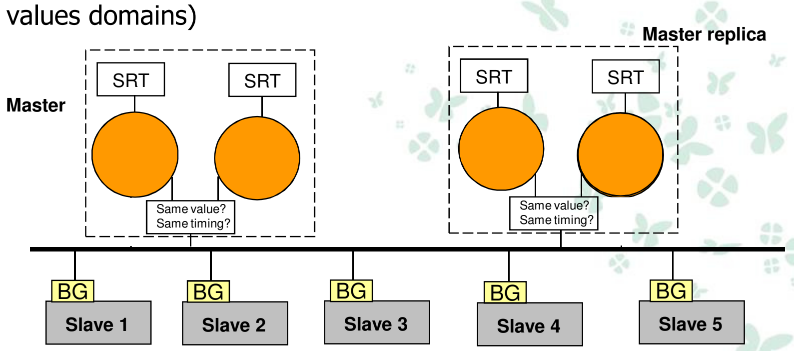
Fault Tolerance in FTT-CAN

- Nodes can fail in arbitrary ways
- Need to enforce fail-silence failure modes:
  - Bus guardians for the slave nodes (fail-silence in the time domain)
  - Internal replication of the master node (fail-silence in time and values domains)



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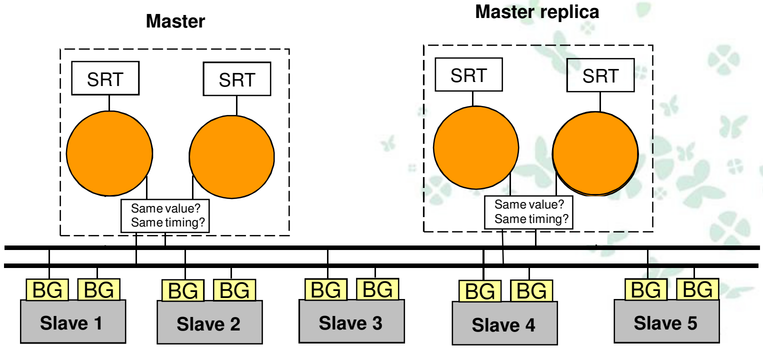
Fault Tolerance in FTT-CAN

- Bus is also a single point of failure:
  - Needs to be replicated



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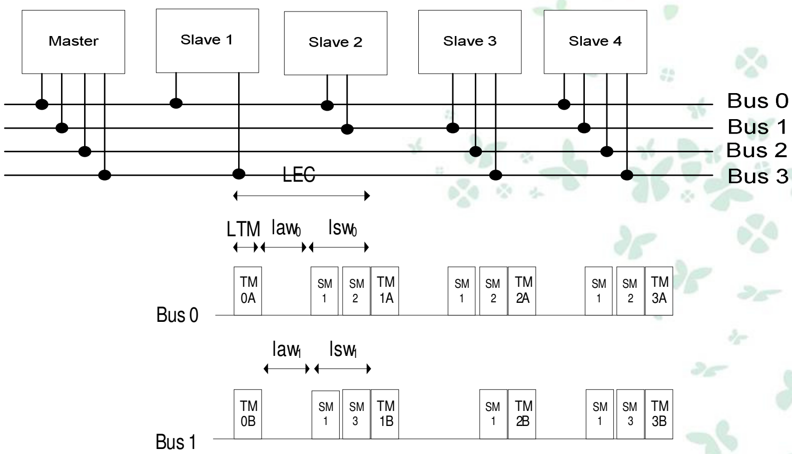
Exploiting Bus redundancy

- Additional bandwidth / message redundancy / adaptive network topology
  - Master connects/ controls all the buses, slaves to all or just a subset.
  - Different traffic in different buses.



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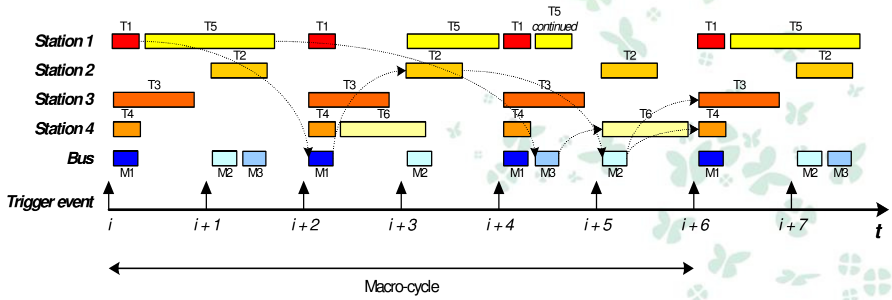
FTT-CAN holistic scheduling

- Synchronized task and message dispatching:
  - Controls interactions among tasks and messages, optimizing bus and processors usage.



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Ethernet in Automation

- Why Ethernet is becoming the prevalent technology in automation networks?
  - Standardized, mature field-proven technology
  - Many technology suppliers
  - Well-known technology: widely available expertise and tools
  - Large bandwidth, with clear path for future expansion, enough to satisfy the forecast needs
  - Appealing price/performance relationship
  - Several extensions for real-time operation
    - Operation at the fieldbus level enabled

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RT Ethernet Technologies

- Real-time extensions to Ethernet (RTE)
  - Use COTS Ethernet switches with careful planning (e.g. Ethernet/IP)
  - No hard guarantees, poor bandwidth utilization
- Traffic shaping in the end nodes
  - e.g. Linux Traffic Control (prevents memory overflows but still suffers from high jitter due to the FIFO queues)
- Master-slave
  - E.g. EtherCAT, Ethernet Powerlink (not compatible with ordinary Ethernet nodes, limitations to the traffic types supported)
- Enhanced switches
  - TT-oriented (PROFINET-IRT, TTEthernet)
  - ET-oriented (AFDX, AV-Bridges)

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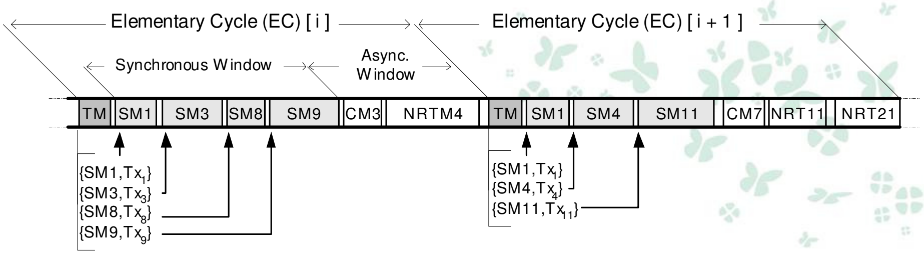
FTT - Ethernet

- The synchronous window conveys the time-triggered traffic
- The asynchronous window conveys:
  - Event triggered traffic, arbitration based on waiting times
  - Non real-time traffic, polled by the Master node



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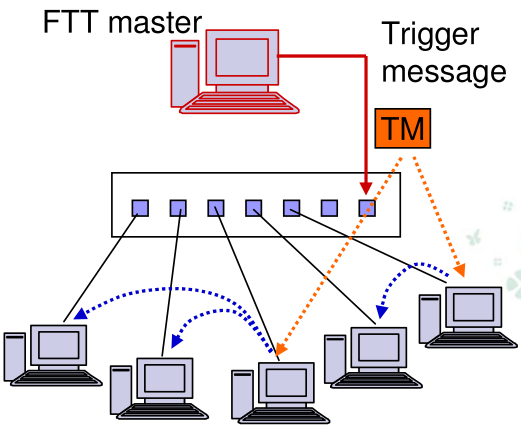
FTT – SE (Switched Ethernet)



- Global traffic coordination:
  - In a common timeline
  - Master synchronizes all nodes
- Arbitrary scheduling policies
  - Priority-based scheduling (FP, EDF,...),
  - Server-based scheduling...
- Different traffic classes
  - real-time, non real-time,
  - synchronous and asynchronous,
  - with strict temporal isolation
- Online admission control
- Dynamic QoS management

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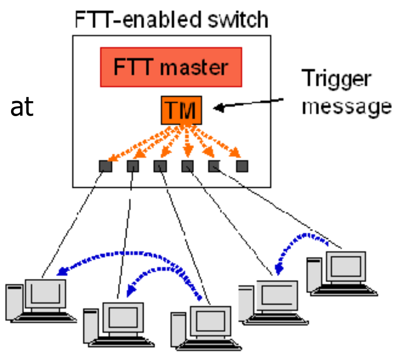
FTT-enabled / HaRTES switch

- HaRTES – Hard Real-Time Ethernet Switch (with FTT services)
  - Legacy / non-FTT compliant nodes can be integrated without jeopardizing the real-time services – traffic isolation
  - Legacy / non-FTT compliant nodes may receive real-time services – virtual real-time channels
- Traffic Policing
  - Unauthorized transmissions blocked at the switch input ports



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Wireless Communications

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Wireless communications

- Emergence of wireless in the 2.4 GHz band:
  - 802.11 / WiFi
  - 802.15.4 and higher level protocols (e.g. ZigBee)
  - Industrial Automation specific protocols (e.g. WirelessHART)
  - Bluetooth!!
- Many applications require R-T and dependable operation:
  - Industrial automation, health, vehicular, …;
- Coping with open environments:
  - Vulnerability to intentional/non-intentional interference from other contention based-technologies, even adopting frequency agility mechanisms.

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Real-Time Communic. on 802.15.4

- Motivation:
  - Wireless opens a wide range of applications.
  - Much lower installation costs and adequate to retrofit.
  - Cost per node drops every day.
  - Possibility to adapt previous research from cabled based communications.
- The Bandjacking technique (for 802.11 and 802.15.4):
  - Instead of avoiding collisions with best-effort traffic, a real-time station acts as an "authority" to "capture" the medium;
  - This station controls the message dispatching from simpler nodes using an adaptation of the FTT – Flexible Time-Triggered protocol (WFTT – Wireless …) in a master-slave fashion.

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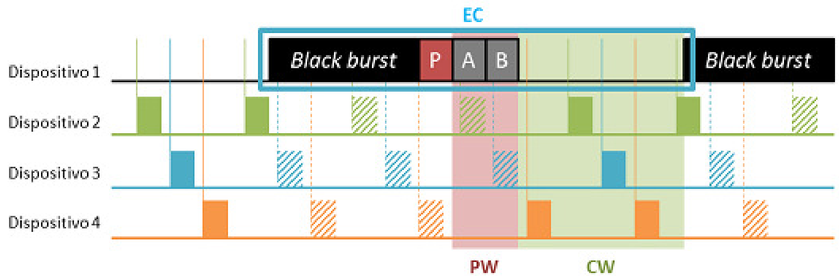
Real-Time Communic. on 802.15.4

Bandjacking and the Wireless FTT Protocol



EC – Elementary Cycle
P – Trigger Message
A, B – Slave messages

PW – Protected Window
CW – Contention Window

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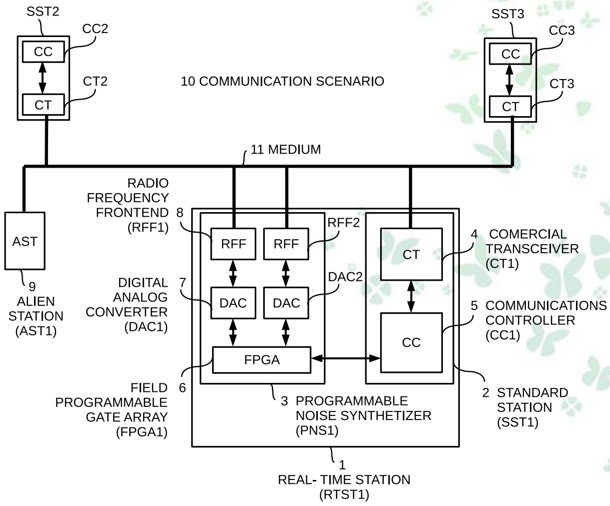
Real-Time Communic. on 802.15.4



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Real-Time Communic. on 802.15.4

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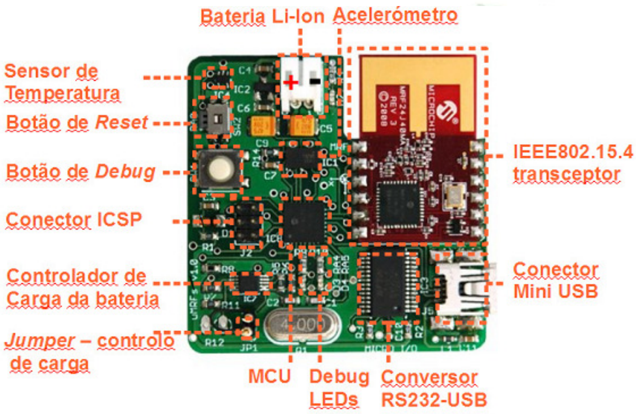

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Vehicular Communications

- Significant increase in vehicular **Dedicated Short Range Communications (DSRC)** expected for the next years
  - safety, comfort, infotainment services.
- Vehicular DSRC protocols and technologies must allow:
  - Vehicle to Vehicle (V2V),
  - Vehicle to Infrastructure (V2I)
  - Infrastructure to Vehicle (I2V)
- Very heterogeneous vehicular scenarios:
  - High dependability and real-time features
  - To support safety critical services
  - Adequate levels of quality of service for the users

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Vehicular Communications: WAVE

- WAVE: Wireless Access to Vehicular Environments
- WAVE Standards:
  - IEEE Std 1609-4 Multi-Channel Operation.
  - IEEE Std 1609-3 Networking Services.
  - IEEE Std 1609-2 Security Services for Applications and Management Messages.
  - IEEE Std 1609-1 Resource Manager (RM).
  - IEEE Std 1609-11 (payments) and 1609-0 (Architecture).
  - IEEE Std 802.11p (MAC and PL).
- Communication @ 5.9GHz
- Spectrum released in Europe in 2008 to enable WAVE (already available in USA and Japan).

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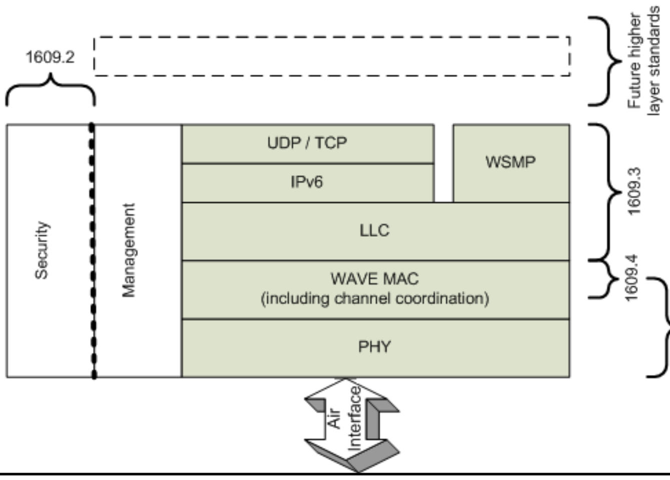
Vehicular Communications: WAVE OBUs

- DSRC: Dedicated Short Range Communications
- WAVE: Wireless Access for Vehicular Environments



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Vehicular Communications: WAVE

- WAVE enables new ITS (Intelligent Transportation Systems) applications.
- Comfort/infotainment applications.
- Tolling
- Safety applications:
  - Emergency Electronic Brake Light,
  - Lane Change Assistance,
  - Post-crash Warnings,
  - Sign Extension Services,
  - Wrong Way Warning,
  - Road Blocked Warning,
  - Intersection Collision Warnings,
  - …

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Vehicular Communications: WAVE OBUs

- The Headway Project
  - Funded by industry
  - Acquiring technology to develop WAVE On Board Units (OBUs) and Road Side Units (RSUs).
- Motivation:
  - Few and expensive off-the-shelf solutions.
  - Own technology enables to propose solutions that may condition the hardware design and the protocols themselves.
  - Progressive deployment, coping with the WAVE standard evolution.
  - Possible large-scale business not only in vehicular (see CAN).
- Current status
  - OBUs (On-Board Units) being finished (3rd generation).

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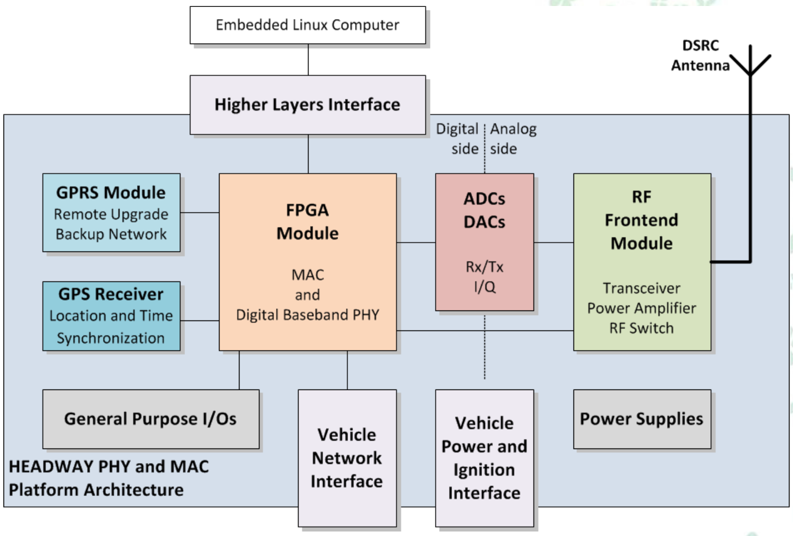
WAVE OBUs Architecture



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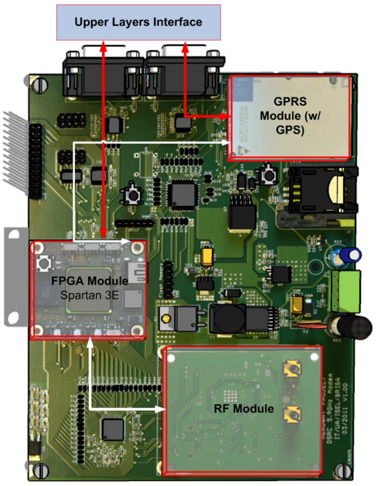
Headway OBUs Prototype



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Safety services

- Safety services in ITS have different requirements of **latency**, **range** and **type of communication.**
- Final report of the **Vehicle Safety Communications Project***:
  - Intersection Collision Avoidance,
  - Public Safety,
  - Sign Extension, Vehicle Diagnostics and Maintenance,
  - Information from Other Vehicles,
- Total of **36** different **safety applications.**
- Focus on urban **motorway scenarios,**
  - **High travelling speed of the vehicles**

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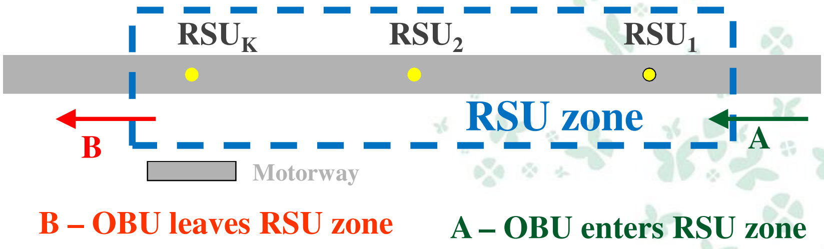
Safety services on top of WAVE

Full RSU covered motorway area (RSU Zone)



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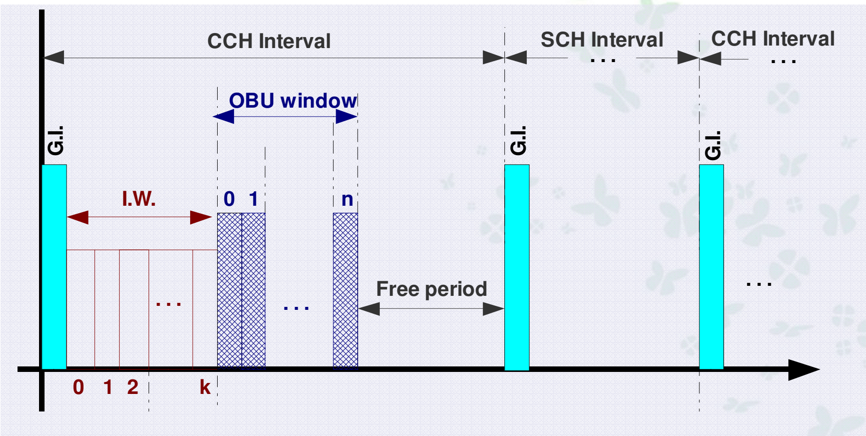
Safety services on top of WAVE



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CONCLUSIONS

- Fieldbuses and Ethernet for Industrial Automation
  - Evolution frozen by standardization wars.
  - Deployment of new solutions takes time (return of investment).
- Wireless communications in open environments
  - Solutions to achieve real-time behavior seem possible.
  - Dissemination in applications such as automation, health, …
- Vehicular Communications: an emergent field
  - Large market, possible spreading for other fields (e.g. CAN).
  - Own transceiver technology: working at low level in the stack.
  - Infrastructure based solution (I2V, V2I) more viable in a few years.
  - Role not only of WAVE but also of 802.15.4.

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THANK YOU

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