

LCPC WIRELESS SENSOR NETWORK PLATFORM

**A generic concept for distributed and
Wireless Sensor Networks**

Organization :

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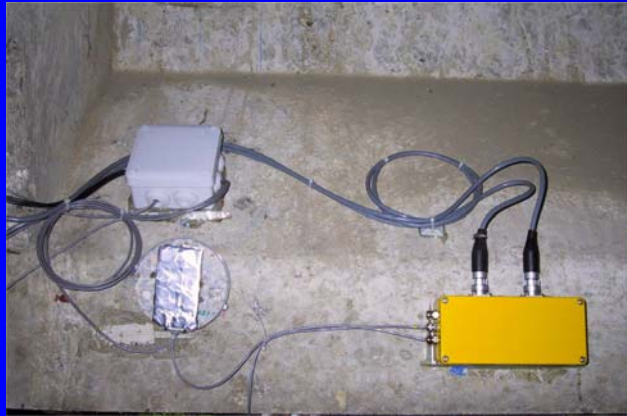
*** LCPC - Instrumentation Division**

Synopsis

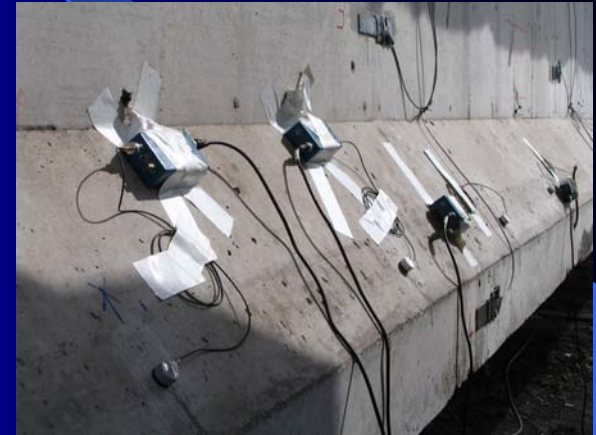
- **Motivation and needs**
- **LCPC platform description**
- **Applications : real case implementations**
- **Prospects and extensions**
- **Conclusion**

Motivation and needs

Even if use of sensors (for Structural Health Monitoring) is a need and a reality, cables of **wired instrumentations** are a source of limitations.



Wires



- > Poor flexibility
- > Geographically limited



Motivation and needs

Other wire limitations :

- Fragile (wind, age...),
- Sensitive to electromagnetic noise,
- Non-massive instrumentations.

From outside the bridge...



...to inside the bridge.



Thus, wireless instrumentation emerges as a source of progress.

Motivation and needs

Wireless technologies are more than a practical simplification !

Wireless technologies are **in adequation with** growing needs and developments of **smart sensors and distributed networks**.



What is a smart sensor ?

- Embeds electronic for digitalization and conditioning
- Embeds softwares (from algorithms to embedded OS),
- Allows numerical and reliable communications through a network (with a supervisor and/or other sensors).

Motivation and needs

Zoom on the « network » topology contributions

The level of abstraction offered by a network protocol allows :

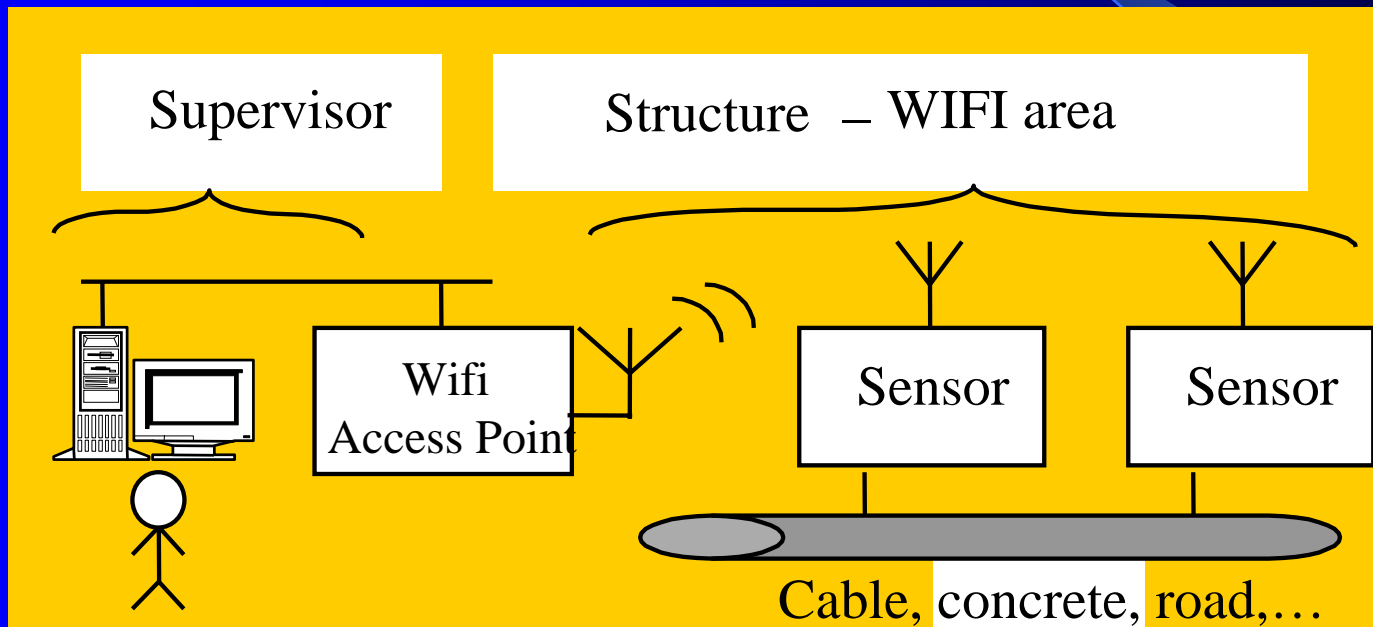
- Durable and evolutionary instrumentation,
- Flexible instrumentation during all the structure lifespan,
- Large number of sensors (more than in “non-networked” sensor systems) and scalability
- Heterogeneous sensors (temperature, wind, strain gauges, accelerometers,...)
- Larger physical deployments (until 1km is realistic)

Stonecutter bridge : 1000 sensors !



LCPC Wireless platform description

LCPC developed such a wireless sensor network platform with the following characteristics : **the platform is a “N sensors 1 supervisor” distributed network.**



Sensors are seen like the computers of a traditional computer network

LCPC Wireless platform description

LCPC wireless platform elements description :

- Network communication
- Smart sensor
- Supervisor

Real case applications



LCPC Wireless platform description

Network communication : TCP/IP world standard protocol !

⇒ Point to point and reliable protocol,

⇒ Independent of its physical implementation : OSI model

7	Application	e.g. <u>HTTP</u> , <u>SMTP</u> , <u>SNMP</u> , <u>FTP</u> , <u>Telnet</u> , <u>NFS</u>
6	Presentation	e.g. <u>XDR</u> , <u>ASN.1</u> , <u>SMB</u> , <u>AFP</u>
5	Session	e.g. <u>RPC</u> , <u>NetBIOS</u> , <u>ASP</u>
4	Transport	e.g. <u>TCP</u> , <u>UDP</u> , <u>RTP</u> , <u>SPX</u> , <u>ATP</u>
3	Network	e.g. <u>IP</u> , <u>ICMP</u> , <u>X.25</u> , <u>CLNP</u> , <u>ARP</u> , <u>RIP</u> , <u>IPX</u>
2	Link	e.g. <u>Ethernet</u> , <u>Token Ring</u> , <u>Zigbee</u> , <u>Wifi</u>
1	Physical	e.g. <u>électronique</u> , <u>radio</u> , <u>laser</u>

LCPC Wireless platform description

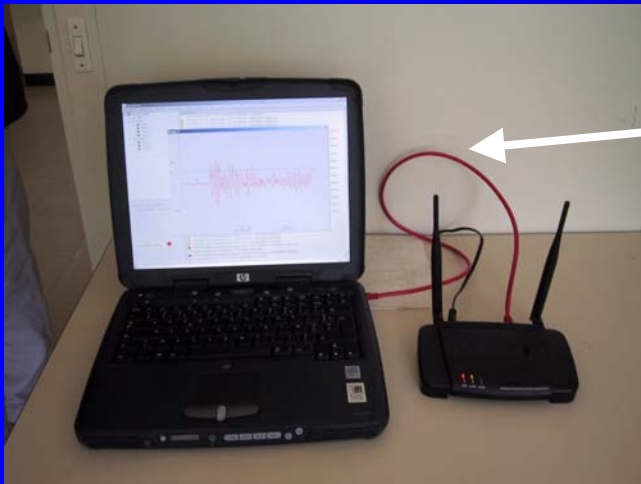
Network communication : TCP/IP

Wireless implementation of TCP/IP exists : WIFI (802.11x)

TCP/IP is an open-source low-cost world-wide protocol

Embeddable and customizable in small electronic components

Wifi are easily adaptable to Bridges context

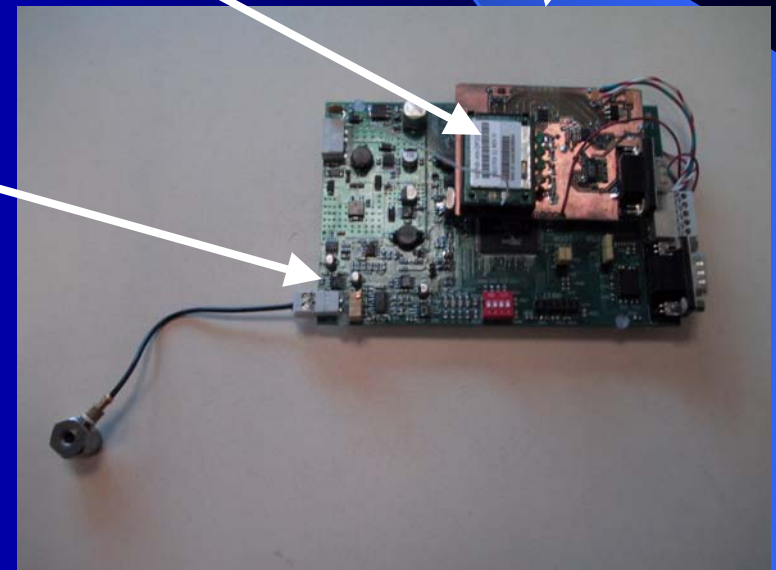


A simple access point connected to a traditional PC provides a wireless TCP/IP area.

LCPC Wireless platform description

LCPC smart sensor:

- Sensor core is a DSP : dedicated to signal processing (FFT, filtering...). Hosts an OS
- DSP embedd the real-time μ Linux OS. Permanently runs the **application** algorithms
- A TCP/IP – Wifi module for wireless communications
- A 12 bits converter that runs data digitalization up to 1 Mhz. Sensitive element : piezzo, strain-gauges, T^oc...
- A GPS module for sensor absolute time synchronization



LCPC Wireless platform description

Supervisor :

- An Oriented Object developed software : easily able of customization from one **application** to another. Reusable software bricks.
- Runs on any standard PC : that all include a native TCP/IP stack = communication with sensors is **fully transparent**
- Offers intuitive interfaces to **manage and configure the sensor network** :
 - To add/remove sensors object in the monitoring system
 - To change a sensor parameter,
 - To dis/enable a sensor in the network,



LCPC Wireless platform description

LCPC platform main contributions :

Abstraction : TCP/IP protocole makes the supervisor-sensors system independent of the physical link (wired or wireless) and of the distance (from meters to 1 km)

Transparent communications : applications hosted by the platform fully profit from the abstraction level of the network protocole.

Important : Thanks to the embedded OS and the TCP/IP protocole, running softwares can be upgraded without uninstalling the sensor of the structure.

Generic : Platform could host different types of sensitive elements : piezzo-electric, anemometer, strain gauges, etc.

High time synchronisation (1 μ s) thanks to GPS module



Application 1 : cable crack monitoring

Goals of the system :

Safety, Structure durability, Cost efficiency

Knowing the number of wire breaks and their location in cables contributes to understand the well-being of the structure

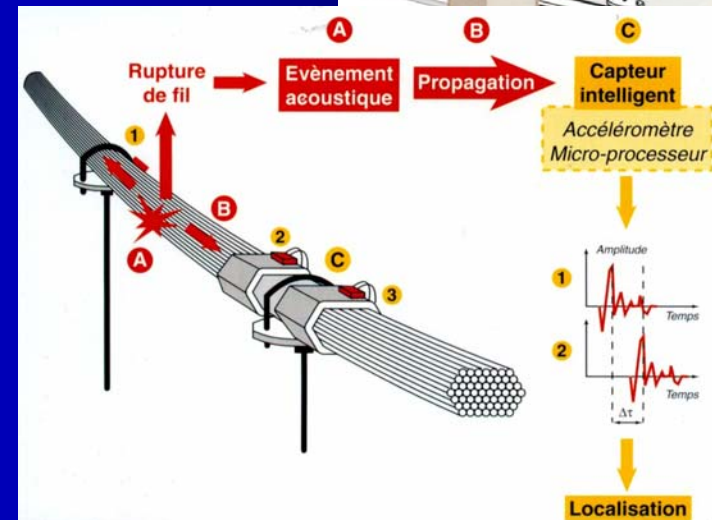
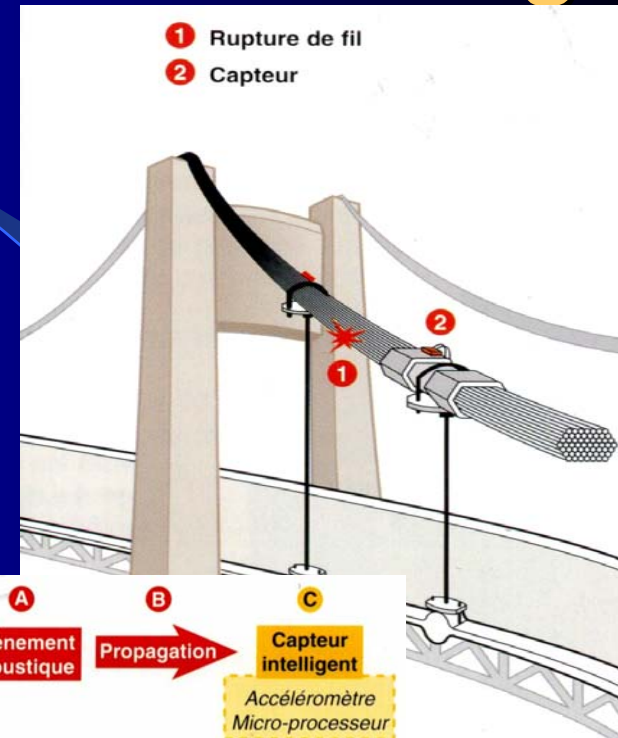
To provide a health monitoring of cables by an acoustic surveillance.



Application 1 : cable crack monitoring

Principle of detection by sensors :

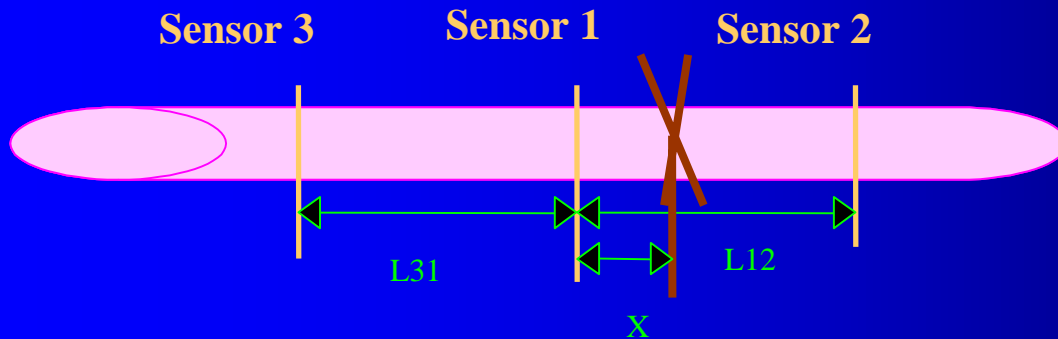
- When a wire breaks, an acoustic wave is generated,
- Wave is detected by sensors, recorded (during 8ms) and very precisely dated,
- Then, sensors transmit those informations to a remote supervisor
- By 3 acoustic sensors informations, supervisor is able to evaluate when and where a rupture occurred



Application 1 : cable crack monitoring

Principle of localization by supervisor :

- Wave speed “S” is estimated by informations from sensor 1 and 3,
- Localization “X” is evaluated between sensor 1 and 2



$$S = L31 / \Delta t31$$

$$X = \frac{1}{2} * (L12 - S * \Delta t12)$$

Application 1 : cable crack monitoring

- Sensors are 10m equispaced,
- Threshold is about 0.8g,
- Speed wave is about 5000 m/s



Contrôle en temps réel
de la sécurité
des ponts suspendus

Tancarville Bridge



Iseron Bridge

**Result : an accuracy of +/-15cm
in wire breaks evaluation.**

Application 1 : cable crack monitoring

Instrumentation of Merlebach Bridge by the wire and the wireless version of the SHM platform.

Sensor distribution



Wireless version

Wire version



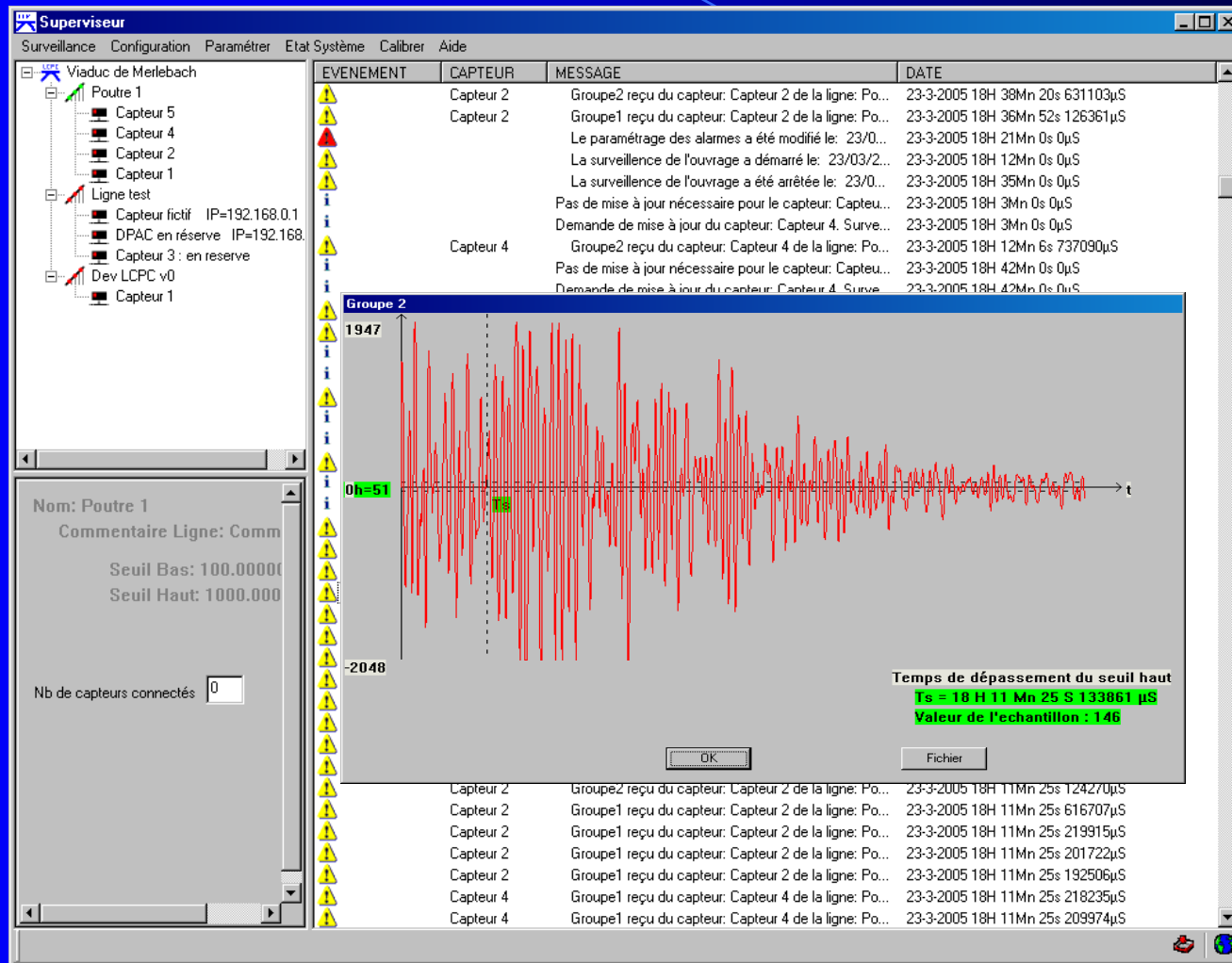
Application 1 : cable crack monitoring

The screenshot shows the 'Superviseur' software interface. On the left, a tree view displays the structure of the 'Viaduc de Merlebach' project, including 'Poutre 1' with five sensors (Capteur 1-5) and a 'Ligne test' with various components. A detailed view for 'Poutre 1' is shown below the tree, including a comment field and sensor status indicators.

The main window displays a table of events with the following columns: EVENEMENT, CAPTEUR, MESSAGE, and DATE. The table contains numerous entries, including sensor data reception and alarm configuration messages.

EVENEMENT	CAPTEUR	MESSAGE	DATE
	Capteur 2	Groupe2 reçu du capteur: Capteur 2 de la ligne: Po...	23-3-2005 18H 38Mn 20s 6311103µS
	Capteur 2	Groupe1 reçu du capteur: Capteur 2 de la ligne: Po...	23-3-2005 18H 36Mn 52s 126361µS
		Le paramétrage des alarmes a été modifié le: 23/0...	23-3-2005 18H 21Mn 0s 0µS
		La surveillance de l'ouvrage a démarré le: 23/03/2...	23-3-2005 18H 12Mn 0s 0µS
		La surveillance de l'ouvrage a été arrêtée le: 23/0...	23-3-2005 18H 35Mn 0s 0µS
		Pas de mise à jour nécessaire pour le capteur: Capteu...	23-3-2005 18H 3Mn 0s 0µS
		Demande de mise à jour du capteur: Capteur 4. Surve...	23-3-2005 18H 3Mn 0s 0µS
	Capteur 4	Groupe2 reçu du capteur: Capteur 4 de la ligne: Po...	23-3-2005 18H 12Mn 6s 737090µS
		Pas de mise à jour nécessaire pour le capteur: Capteu...	23-3-2005 18H 42Mn 0s 0µS
		Demande de mise à jour du capteur: Capteur 4. Surve...	23-3-2005 18H 42Mn 0s 0µS
	Capteur 4	Groupe1 reçu du capteur: Capteur 4 de la ligne: Po...	23-3-2005 18H 11Mn 49s 238350µS
	Capteur 4	Groupe1 reçu du capteur: Capteur 4 de la ligne: Po...	23-3-2005 18H 11Mn 46s 818184µS
		Pas de mise à jour nécessaire pour le capteur: Capteu...	23-3-2005 18H 33Mn 0s 0µS
		Demande de mise à jour du capteur: Capteur 4. Surve...	23-3-2005 18H 33Mn 0s 0µS
	Capteur 4	Groupe2 reçu du capteur: Capteur 4 de la ligne: Po...	23-3-2005 18H 11Mn 37s 163034µS
		Pas de mise à jour nécessaire pour le capteur: Capteu...	23-3-2005 18H 26Mn 0s 0µS
		Demande de mise à jour du capteur: Capteur 4. Surve...	23-3-2005 18H 26Mn 0s 0µS
	Capteur 4	Groupe2 reçu du capteur: Capteur 4 de la ligne: Po...	23-3-2005 18H 11Mn 32s 866441µS
		Pas de mise à jour nécessaire pour le capteur: Capteu...	23-3-2005 18H 26Mn 0s 0µS
		Demande de mise à jour du capteur: Capteur 5. Surve...	23-3-2005 18H 26Mn 0s 0µS
	Capteur 5	Groupe2 reçu du capteur: Capteur 5 de la ligne: Po...	23-3-2005 18H 11Mn 25s 141605µS
	Capteur 5	Groupe2 reçu du capteur: Capteur 5 de la ligne: Po...	23-3-2005 18H 11Mn 25s 133861µS
	Capteur 1	Groupe2 reçu du capteur: Capteur 1 de la ligne: Po...	23-3-2005 18H 11Mn 25s 141199µS
	Capteur 2	Groupe2 reçu du capteur: Capteur 2 de la ligne: Po...	23-3-2005 18H 11Mn 25s 139758µS
	Capteur 4	Groupe2 reçu du capteur: Capteur 4 de la ligne: Po...	23-3-2005 18H 11Mn 25s 140920µS
	Capteur 4	Groupe2 reçu du capteur: Capteur 4 de la ligne: Po...	23-3-2005 18H 11Mn 25s 133177µS
	Capteur 1	Groupe2 reçu du capteur: Capteur 1 de la ligne: Po...	23-3-2005 18H 11Mn 25s 133185µS
	Capteur 2	Groupe2 reçu du capteur: Capteur 2 de la ligne: Po...	23-3-2005 18H 11Mn 25s 132014µS
	Capteur 4	Groupe2 reçu du capteur: Capteur 4 de la ligne: Po...	23-3-2005 18H 11Mn 25s 125433µS
	Capteur 5	Groupe2 reçu du capteur: Capteur 5 de la ligne: Po...	23-3-2005 18H 11Mn 25s 126104µS
	Capteur 5	Groupe1 reçu du capteur: Capteur 5 de la ligne: Po...	23-3-2005 18H 11Mn 25s 209974µS
	Capteur 1	Groupe2 reçu du capteur: Capteur 1 de la ligne: Po...	23-3-2005 18H 11Mn 25s 125442µS
	Capteur 2	Groupe2 reçu du capteur: Capteur 2 de la ligne: Po...	23-3-2005 18H 11Mn 25s 124270µS
	Capteur 2	Groupe1 reçu du capteur: Capteur 2 de la ligne: Po...	23-3-2005 18H 11Mn 25s 616707µS
	Capteur 2	Groupe1 reçu du capteur: Capteur 2 de la ligne: Po...	23-3-2005 18H 11Mn 25s 219915µS
	Capteur 2	Groupe1 reçu du capteur: Capteur 2 de la ligne: Po...	23-3-2005 18H 11Mn 25s 201722µS
	Capteur 2	Groupe1 reçu du capteur: Capteur 2 de la ligne: Po...	23-3-2005 18H 11Mn 25s 192506µS
	Capteur 4	Groupe1 reçu du capteur: Capteur 4 de la ligne: Po...	23-3-2005 18H 11Mn 25s 218235µS
	Capteur 4	Groupe1 reçu du capteur: Capteur 4 de la ligne: Po...	23-3-2005 18H 11Mn 25s 209974µS

Application 1 : cable crack monitoring



Application 1 : cable crack monitoring

Result : a complete chain that ensure cable crack monitoring !



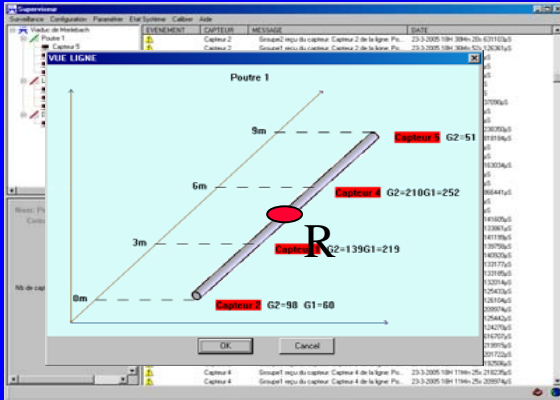
Sensor detection



Wave digitalization



TCP/IP
Wifi transmission



Supervisor analyses

N° evt	heure	capteur	position	vitesse	ampl. Crete	ampl. Max	charge	observation
1	14:59:59	5	163	4992	11	222	95-90	plusieurs fils
2	15:00:00	6	-164	4581	32	123	85-90	plusieurs fils
3	15:00:31	6	-104	4716	7	53	85-90	plusieurs fils
4	15:00:46	6	-163	5067	8	36	85-90	plusieurs fils
5	16:45:18	6	-164	4660	6	129	90-96	plusieurs fils
6	16:47:53	6	-8	2344	3	15	90-96	à voir ?
7	16:50:06	6	-40	5057	10	175	90-96	plusieurs fils
8	17:37:21	3	68	5295	5	19	95-100	2 fils
9	17:58:12	6	-77	2715	2	7	95-100	1 fil
10	17:58:26	6	-77	5154	4	79	95-100	plusieurs fils
11	18:00:05	6	-20	5766	13	42	100-105	plusieurs fils
12	18:00:23	6	-81	5021	15	96	100-105	plusieurs fils
13	18:00:51	6	-136	5520	5	124	100-105	plusieurs fils
14	18:01:40	6	-90	5192	4	79	100-105	plusieurs fils
15	18:02:37	6	43	4498	4	62	100-105	plusieurs fils
16	18:03:53	6	-157	6021	9	41	100-105	plusieurs fils

Structure diagnosis

Application 2 : Intelligent wireless traffic and infrastructure monitoring (ITS)

Goals of the system :

Safety, traffic monitoring

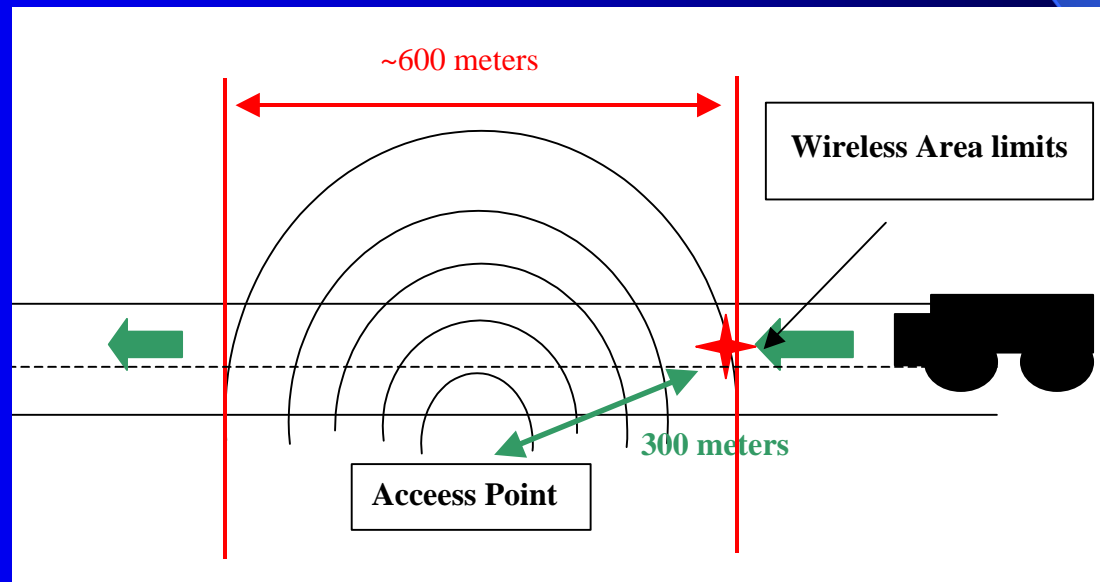
Vehicule-Infrastructure-Driver
communication

To provide a prototype of a
wireless traffic monitoring
system of a road section



Application 2 : Intelligent wireless traffic and infrastructure monitoring (ITS)

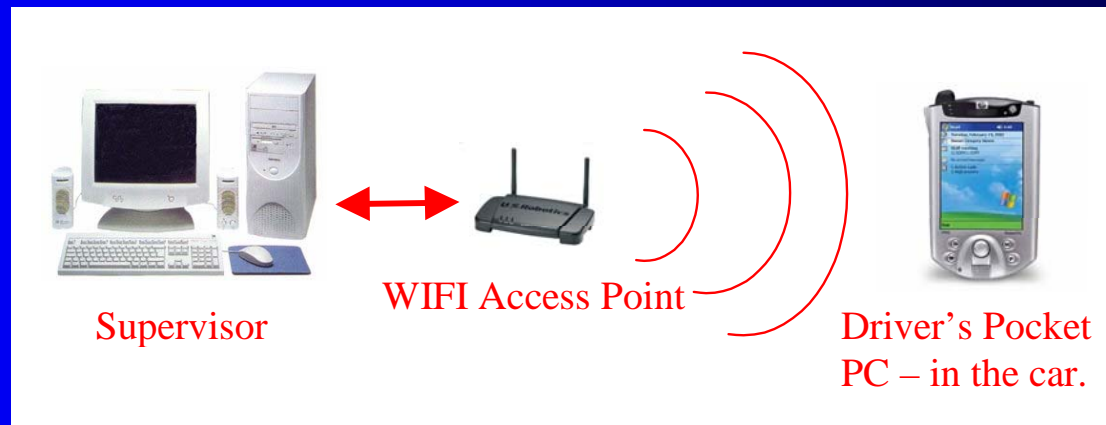
LCPC Wireless Platform is implemented as a WIFI Local Area Network (LAN) provider, through which, drivers can **receive or transmit security informations.**



Application 2 : Intelligent wireless traffic and infrastructure monitoring (ITS)

Wireless platform is made of the following elements :

- The Oriented Object Language Supervisor (adapted to the context), running on a PC
- An Access Point that ensures the TCP/IP Wireless (Wifi) Area on a road section,
- In his car, driver's interface consists in a commercial Pocket PC that embeds the Wifi protocol.



Application 2 : Intelligent wireless traffic and infrastructure monitoring (ITS)



**Car-embedded
Pocket PC**



Wifi Area

Traffic monitoring



Application 2 : Intelligent wireless traffic and infrastructure monitoring (ITS)

Results :

- A prototype and operational wireless **Vehicle-Infrastructure-Driver** communication system,
- A real-time traffic monitoring,
- Algorithms that dynamically detect car entry & exit in the area
- Efficient possibility of transmitting emergency informations to a specific or each car present in the area

Prospects and extensions

Road map and improvements :

- A biggest use of DSP capacities (frequential signature, filtering),
- Add to sensor local sources of energy to perform sensor power autonomy (wind, small solar cells,...)
- Different use of the GPS module (modal analyses,..)
- Testing other way for time synchronization of sensors (NTP V4 protocole,...),
- Keeping the high level TCP/IP protocole but testing new low-level wireless protocole such as Zigbee.

Conclusion

- **Efficient wireless sensor network for monitoring structures,**
- **Taking care of real application conditions is fundamental,**
- **Use of network protocols is a real advantage : high level of abstraction, independent of the physical link, scalability,...**
- **Oriented Object softwares and algorithms is a useful contribution to ensure modularity and reutilisability,**
- **Embedded OS (ucLinux) in sensors offers abstraction and a new way of monitoring : sensors are remotely auto-adaptative**
- **There remain a lot of improvements ! Power autonomy, integration, ...**