Collective Adaptive Systems: Approaches and challenges

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Outline

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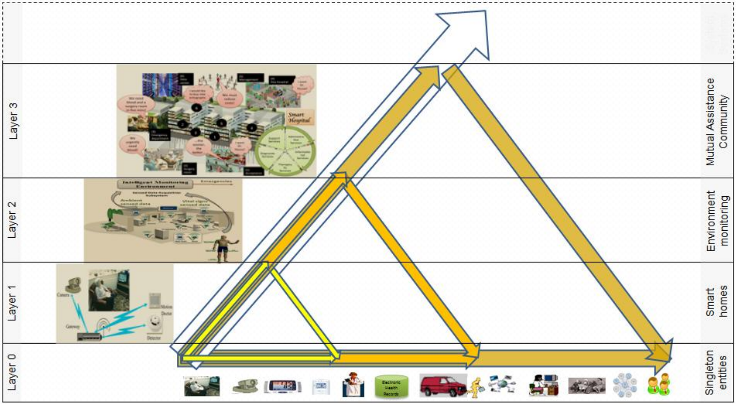
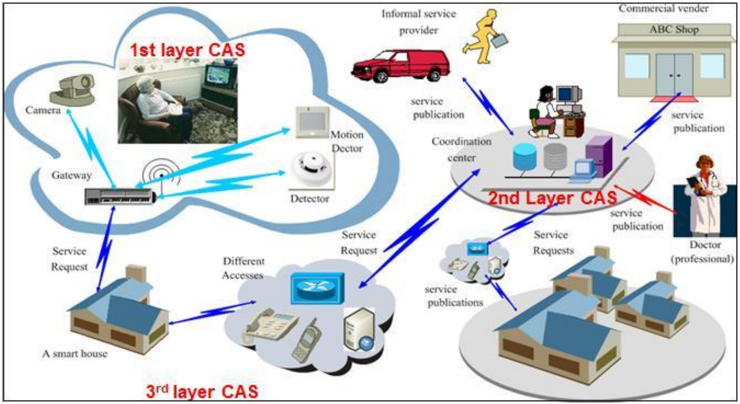
- Socio-technical Collective Adaptive Systems:
  - Composed of different heterogeneous entities (e.g., individuals, groups, computers, software agents, devices, services, sensors) that may join and leave the collective at any time.
  - Entities are operating at different temporal, spatial scales and social scope and interact collectively in complex manner with different objectives and goals.
  - Their ability to be adaptive requires incorporating mechanisms that allow entities to perform actions that may lead to the emergence of a global desired behavior or service, while still managing and controlling the whole system behavior [1,2,3,14].

- CAS can be organized into several layers according to time and space scales, and of increasing levels of complexity [15].

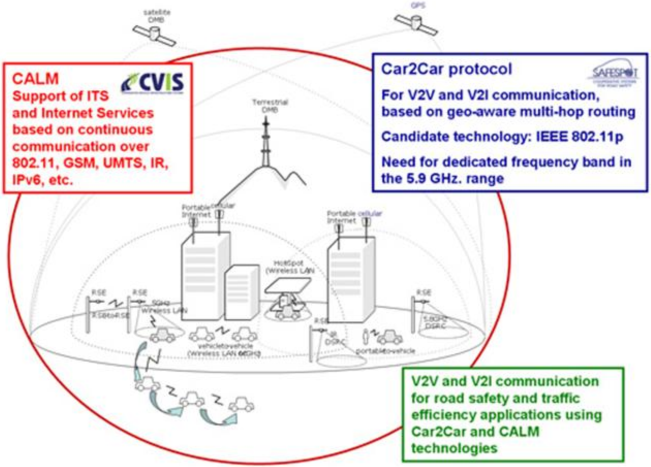


Aspects of CASs	Layer 1 CAS	Layer 2 CAS	Layer 3 CAS
Heterogeneous components	Mainly artificial entities (few human input)	Human, groups of human, artificial services	Communities, networks, social organizations
Many units/nodes	Dozens	Hundreds	Thousands
Unit with conflicting objectives and goals	Unique goal (no conflict)	Independent homogeneous goals with possible conflict	Social heterogeneous conflicting goals involving arbitration
Decision-making	User centric, centralized	Multi-user centric, decentralized	Social centric, decentralized
Emergence and control	Limited emergence and full control	Limited emergence and distributed control	Emergence of unexpected phenomena and fully distributed control
Nodes may join or leave	Rarely	Commonly	Continuously
Time scale	Short term (minutes, hours)	Medium term (from days to weeks and months)	Large (months, years)
Space scale	House / Building	Buildings / City	Metropolitan / Regional
Social scope	Limited	Bounded	Unbounded

- Example: Mutual Assistance Community for Elderly People [15]

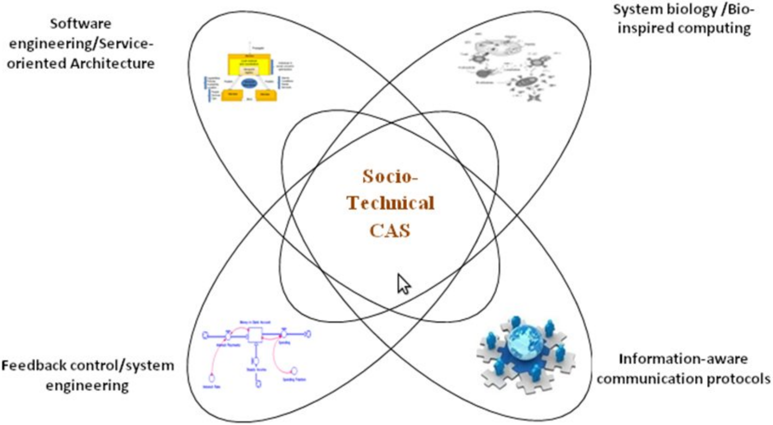


- Example: cooperative driving [17]



Outline

- Principles for engineering CAS are mainly classified into two categories:
  - Design principles are necessary to build and manage the system by enabling the emergence of behaviour and facilitating prediction and control of those behaviours.
  - Operating principles should define techniques that allow the system to operate taking into consideration the diversity of objectives within the system and the need to reason in the presence of uncertainty (e.g., partial, noisy, out-of-date and inaccurate information) [18].


Software engineering/Service-oriented Architecture
System biology /Bio-inspired computing
Socio-Technical CAS
Feedback control/system engineering
Information-aware communication protocols

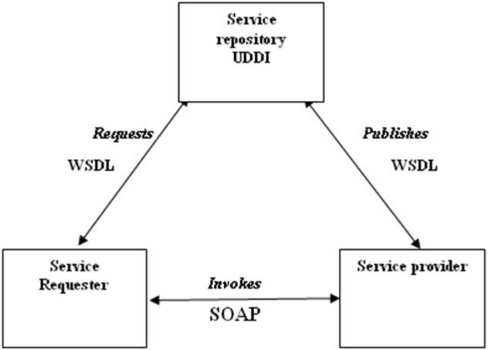
- Information-aware communication protocols [10,11,12]:
  - Sending the right information to the right place.
  - Important information gets automatically replicated and propagated where it is needed.
  - Sending redundant and massive information could also have negative effects (e.g. be stressful, confusing) on their decision making process.

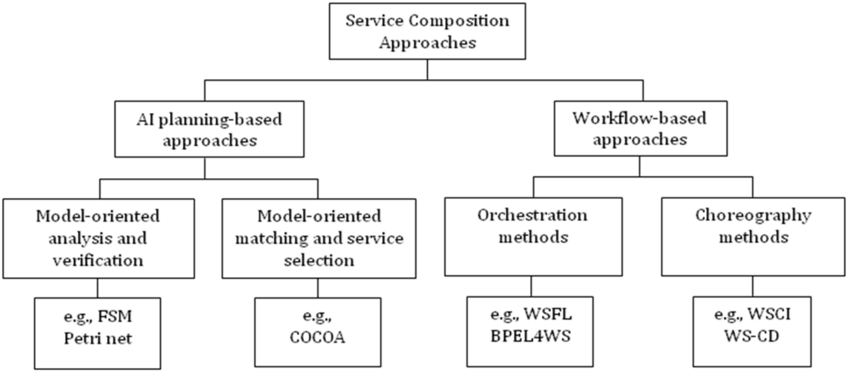
Communication characteristics	Communication technologies									
	Traditional communication technologies								Vehicular communication technologies	
	Infrastructure-based				Infrastructureless					
	GSM/ GPRS	WiMAX	DVB/ DAB	WLANs (a/b/g/n)	MM Wave	IR	ZigBee	Bluetooth	DSRC/ WAVE	CALM (M5)
Communication mode	V2I/ V2V^i	V2I/ V2V^i	I2V	V2V^i	V2R/ V2V^d	V2R/ V2V^d	V2V^d	V2R	V2R/ V2V^d	V2R/ V2V^d
Directionality	2	2	1	1/2	1/2	1/2	1/2	2	1/2	1/2
Latency	1.5–3. 5sec	~110 ms	10–30 sec	~46 ms	~150 µs	Very Low	~16 ms	~100 ms	200 µs	200 µs
Data rate	80–38 4 kb/s	1–32 Mb/s	~1.73 Mb/s	54–600 Mb/s	~1 Gb/s	~1 Mb/s	20–250 kb/s	1–3 Mb/s	~6 Mb/s	~6 Mb/s
Range	10 km	15 km	40 km	250 m	~10 m	~10 m	~100 m	~10 m	~1 km	~1 km
Transmission mode	1/2	1/2	3	1	1	1	1	1	1	1
Mobility	Yes	Yes	Yes	Limited	Limited	No	Yes	Limited	Yes	Yes
Operating band	0.8–1. 9 GHz	5.x GHz	6–8 MHz	2.4–5.2 GHz	60–64 GHz	2.6 GHz	2.4–2.5 GHz	2.4 GHz	5.8–5.9 GHz	5–6 GHz

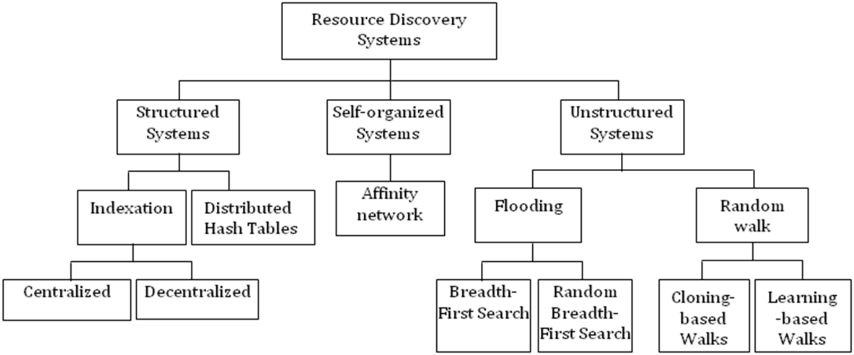
Communication requirements	ITS applications						
	Safety applications			Efficiency applications		Comfort applications	
	Collision avoidance	Road sign notifications	Incident management	Traffic management	Road monitoring	Entertainment	Contextual information
Communication mode	V2V/ V2I^d	I2V^d	V2V/ I2V^d	V2I/ V2I^d	I2V/ I2V^d	I2V	I2V/ V2V^d
Directionality	1/2	1	1	1/2	1	1/2	1/2
Latency	Very low	Low	Low	Low-medium	Low	Average	Medium
Data rate	Medium	Medium	Medium	Low-medium	Low-medium	High	Low-medium
Range	Short	Short	Short-medium	Short-medium	Short-medium	Long	Medium-long
Transmission mode	1	1/3	1/2	1	1/3	1	1
Message reliability	High	High	High	Medium-high	Medium-hgh	Average	Average
Message priority	High	High	High	Medium	Medium	Average	Average

Communication mode		Directionality		Latency		Range		Transmission mode		Data rate	
V2V^d	Vehicle-to-vehicle direct communication	1	One-way	Very low	In microseconds	Short	< 500 m	1	Unicast	High	> 6 Mb/s
V2V^i	Vehicle-to-vehicle indirect communication	2	Two-way	Low	In milliseconds	Medium	~ 1 km	2	Geocast	Medium	1–6 Mb/s
V2I	Vehicle-to-infrastructure	1/2	Both	Average	In seconds	Long	> 1 km	3	Broadcast	Low	< 1 Mb/s

- Service discovery and composition mechanisms [13,14]:
  - Describe how different services can be composed (at design or at runtime) into a coherent global service to satisfy the user request or to respond to changing context or human behaviour.




Service Composition Approaches
AI planning-based approaches
Workflow-based approaches
Model-oriented analysis and verification
Model-oriented matching and service selection
Orchestration methods
Choreography methods
e.g., FSM Petri net
e.g., COCOA
e.g., WSFL BPEL4WS
e.g., WSCI WS-CD


Resource Discovery Systems
Structured Systems
Self-organized Systems
Unstructured Systems
Indexation
Distributed Hash Tables
Affinity network
Flooding
Random walk
Centralized
Decentralized
Breadth-First Search
Random Breadth-First Search
Cloning-based Walks
Learning-based Walks

- Specification, design, and runtime verification of CAS
  - Static verification refers to proving the correctness of formally expressed specifications. Main techniques applied for static verification are Model Checking and Automated Theorem Proving.
  - A relatively new direction of verification is runtime verification, which is defined as "the discipline of computer science that deals with the study, development, and application of those verification techniques that allow checking whether a run of a system satisfies or violates a given correctness property. [8,14,19]"

Characteristic	**Formal Method**			
	Ambient Calculus	Bigraph	Temporal Logics	Ontology
Movements	✓	✓		
Properties VS locations	✓	✓		
Interactions		✓		
Concepts				✓
Relationships	Spatial	Spatial	Temporal	Any
Real-time constraints			✓	

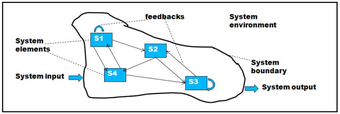
Technique	**Characteristic**	
	Strengths	Weaknesses
Theorem Proving	Complete verification of the specification	State space explosion Possible undecidibility
Model Cheching	Complete verification of the specification	State space explosion Possible undecidibility
Testing Specifications	No state space explosion	Partial verification of the specification
Runtime verification	Executing recovering strategies Partial verification of the implementation	Need of additional components for monitoring

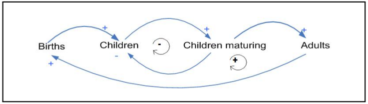
Tools	**Formal Method**			
	Ambient Calculus	Bigraph	Temp. Logics	Ontology
Visual Modelling Tools	✓		✓	✓
Algorithms for Model Checking	✓		✓	
Model Checkers			✓	
Theorem Provers			✓	
Reasoners			✓	✓

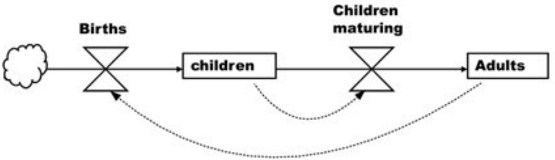
?

- Autonomic computing focuses on creating systems that manage themselves according to an administration goals, e.g., self-CHOP developed using MAPEK mechanism [5].
- Control engineering field, most approaches emphasize positive and negative feedback loops seen also in natural and biological systems.
- Software engineering communities highlighted that feedback loops are core design elements and should be made explicit for modeling, implementation, and validation approaches [4,7].

- Negative and positive feedbacks are combined to insure stability of the system.
- Positive feedback alone pushes the system beyond its limits and eventually out of control while negative feedback alone prevents the system from searching the optimal behavior [20,21].





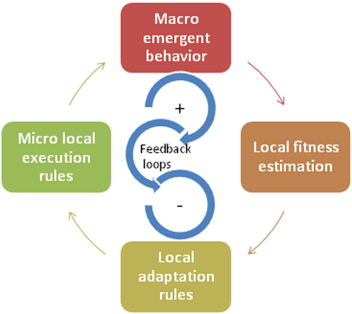


Outline

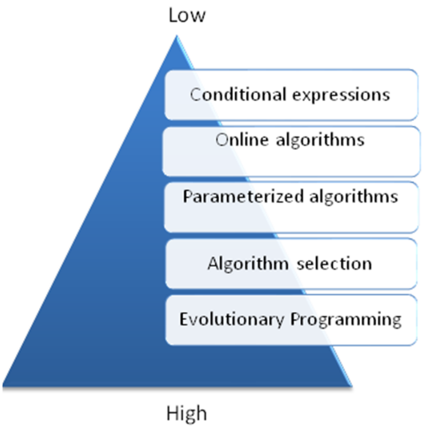
- CASs can be seen as a form of complex systems.
- Complex Systems Science results have been also used only in a limited way by researchers in ICT for designing large-scale distributed adaptive systems.

Designing CAS requires a shift from the current top down design approach to a bottom up design approach. Local rules allow the system's components to collaborate in a distributed manner in order to enable the emergence of behaviors at a global level [1,2].

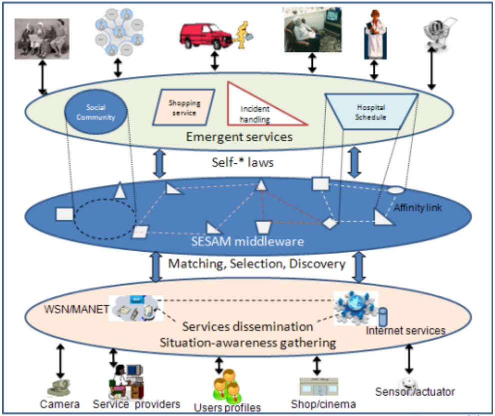
- how to design basic components in which decisions are distributed and not fully controlled by a single component.
- how to design strategies (micro level) that allow the system to adapt to internal/external changes (macro level).
- what are the dynamic rules that drive the system to the expected behavior.



- Several techniques could be used to develop algorithms with increasing level of adaptiveness [16].



- This paradigm shift requires an autonomic middleware that incorporates software elements or agents with adaptive capabilities [13,14].



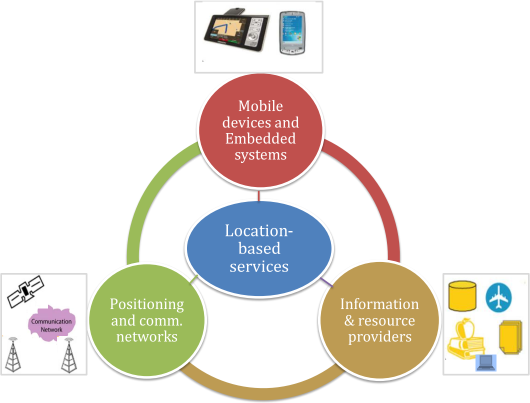
- Get inspired from features and capabilities seen in natural and biological systems, e.g., human brain, immune systems, Ants colony, Flocks of birds.

- BIS provide several features and organizing principles that can guide the design of a scalable, adaptive and efficient framework to bring answers to CAS challenges [6,21].

Outline

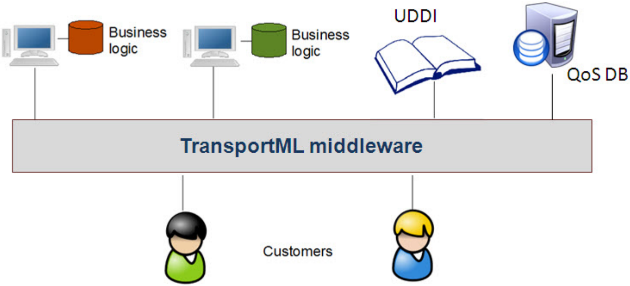
- Increasing the driver safety and comfort by relaying required information using V2V.
- The pervasive availability of wireless communication technologies and handheld devices and the emergence of GNSS infrastructures for LBS.
- A platform and mechanisms are required to facilitate the development and deployment of LBS and hide details about technological infrastructures [9,10].

- For developing such services, different infrastructure components are required: mobile devices, communication networks, positioning components, and service providers.



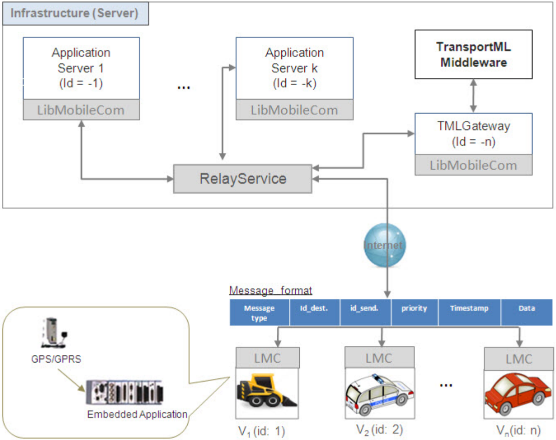
TransportML platform based on SOA principles is developed to enable interaction and collaboration of road-related services.

- Local entities services possess geographical information, which can be stored and formatted in many different ways.
- Service providers must agree on a common communication language: Transportation Markup Language (TransportML).
- TransportML is open, XML-based, extensible and it enables elaboration of the collaboration scenario at execution time.



This architecture allows providing value-added services, resulting from the collaboration between existing services maintained by different transport road entities.

Consists in Relay server and a LibMobileCom (LMC) library for V2I2V communications:



- A prototype is developed as a proof of concept.

Road status

- Provides information regarding the road status, issued by field agents
- Comprises 2 sub-services: snow removal and roadwork services.

Waste Collection Service

- Provides information regarding the real-time location of waste collecting trucks.

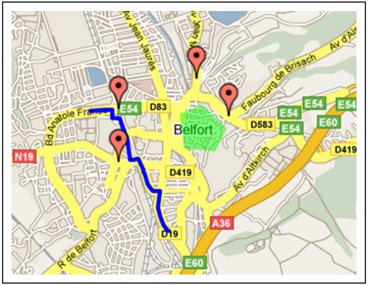
Itinerary Computation Service

- Computes the fastest route between 2 locations
- Allows defining waypoints, advised and discouraged areas.

Geofencing service

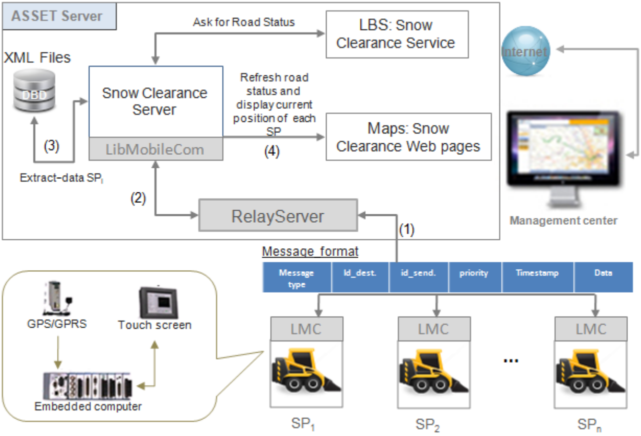
- Provides the characteristics of areas (granted or denied) based on vehicle characteristics.

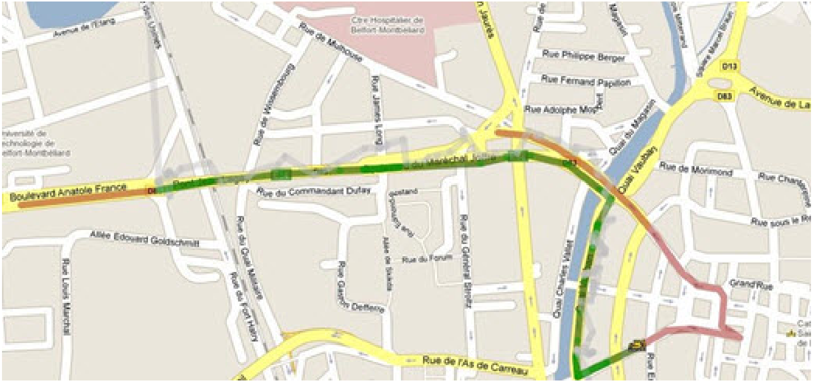
- Computed itinerary by calling LBS,



- When using TransportML, the distance travelled is longer than the distance travelled when TransportML is not used.
- The time required for the same travelling path is lower when TransportML is used.
- The time needed to reach a destination is around 27% less when using TransportML.
- The wireless communication delay versus V2I distance and the vehicle's speed.
- The average communication time is approximately 0.6s.

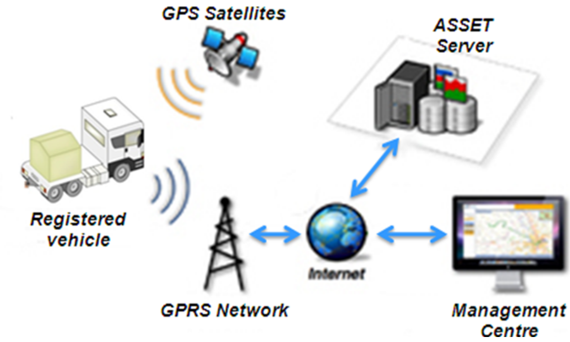
- Track and display in real time the position of snow plow.
- The roads to be cleared are known in advance and are stored in database or XML file.
- Snow clearance service gets the road status whenever is invoked.
- The road status (cleared or not) are based on an algorithm which from the snow plow position computes the unclear part of the itinerary.

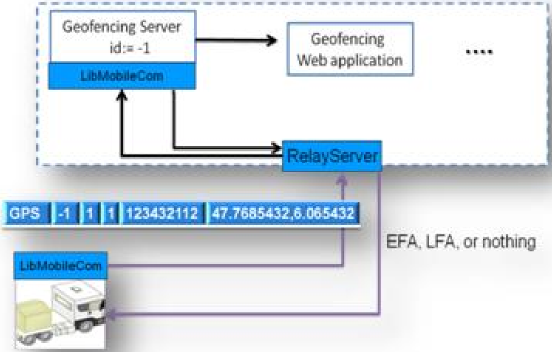

ASSET Server
Ask for Road Status
LBS: Snow Clearance Service
XML Files
DBD
Snow Clearance Server
LibMobileCom
Refresh road status and display current position of each SP
Maps: Snow Clearance Web pages
(3)
(4)
Extract-data SP_i
(2)
RelayServer
(1)
Internet
Management center
Message format
Message type
Id_dest.
id_send.
priority
Timestamp
Data
GPS/GPRS
Touch screen
Embedded computer
LMC
LMC
LMC
...
SP1
SP2
SPn

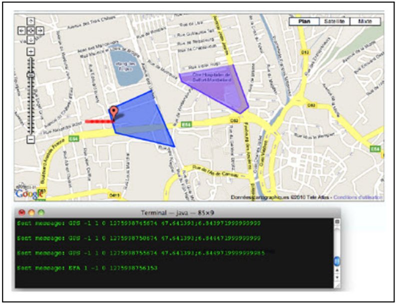

Avenue de l'Etang
Ctre Hospitalier de Belfort Montbéliard
Rue de Mulhouse
Rue Philippe Berger
Rue Fernand Papillon
Rue Adolphe Mo
Avenue de La
D13
D83
Rue James Long
Rue de Wissembourg
Boulevard Anatole France
Rue du Commandant Dufay
Quai Vauban
Quai du Magasin
Rue de Morimond
Rue Charle
Rue sous le Ro
Allée Edouard Goldschmitt
Rue Louis Marchal
Rue du Quai Maillard
Rue du Fort Hardy
Rue Gaston Defferre
Rue du Forum
Rue du Général Strolz
Quai Charles Vallet
Grand'Rue
Rue de l'As de Carreau

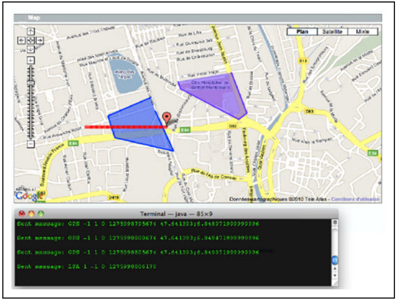
- Define, draw geofences, store them in MySQL database, and represent them on the Map.

- Define the characteristics of the geofences (e.g. max weight, forbidden vehicles).



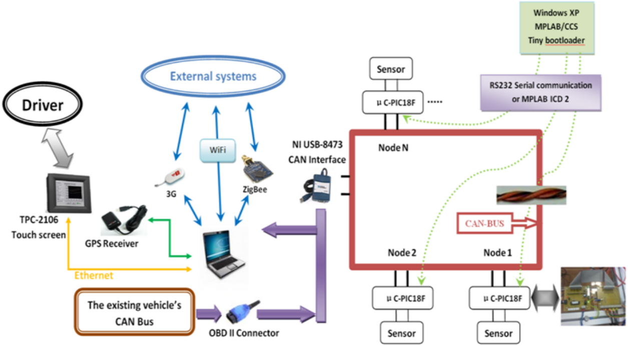

Geofencing Server
id:= -1
LibMobileCom
Geofencing
Web application
....
RelayServer
GPS
-1
1
1
123432112
47.7685432,6.065432
EFA, LFA, or nothing
LibMobileCom


Plan
Satellite
Mixte
Terminal — java — 85×9

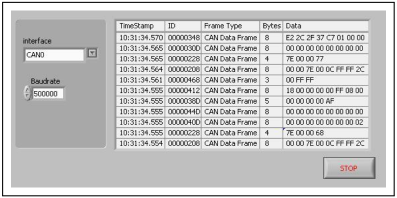

Plan
Satellite
Mixte
Terminal — java — 85×9

- It is hard for drivers to anticipate dangerous situations on the road especially when driving during the night or in the fog, and due to the blurring of vision or at high speed.
- Most of systems are based on centralized architectures and fixed infrastructures on roads.
- Systems with the minimum of deployment cost and the ability for efficient context information transmission and processing are required.
- Exchange information between vehicles experiencing undesirable and/or dangerous situations with other surrounding vehicles.

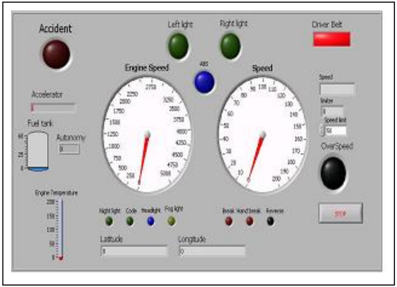
- An in-vehicle embedded software is implemented and tested.
- Extract information from the CAN bus of the vehicle and exchange this information with other nearby vehicles.

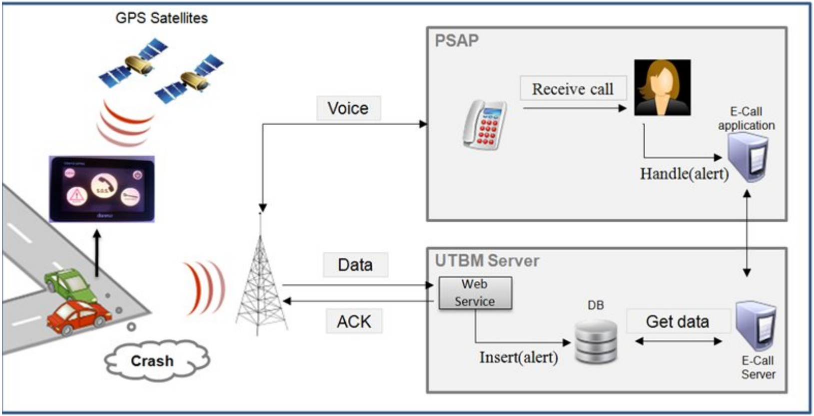


- The data-logger software is developed using LabVIEW for extracting, decoding, and saving the frames coming from the vehicle CAN bus.



TimeStamp	ID	Frame Type	Bytes	Data
10:31:34.570	00000348	CAN Data Frame	8	E2 2C 2F 37 C7 01 00 00
10:31:34.565	0000030D	CAN Data Frame	8	00 00 00 00 00 00 00 00
10:31:34.565	00000228	CAN Data Frame	4	7E 00 00 77
10:31:34.564	00000208	CAN Data Frame	8	00 00 7E 00 0C FF FF 2C
10:31:34.561	00000468	CAN Data Frame	3	00 FF FF
10:31:34.555	00000412	CAN Data Frame	8	18 00 00 00 00 FF 08 00
10:31:34.555	0000038D	CAN Data Frame	5	00 00 00 00 AF
10:31:34.555	0000044D	CAN Data Frame	8	00 00 00 00 00 00 00 00
10:31:34.555	0000040D	CAN Data Frame	8	00 00 00 00 00 00 00 02
10:31:34.555	00000228	CAN Data Frame	4	7E 00 00 68
10:31:34.554	00000208	CAN Data Frame	8	00 00 7E 00 0C FF FF 2C




GPS Satellites
Voice
PSAP
Receive call
E-Call application
Handle(alert)
Data
ACK
UTBM Server
Web Service
DB
Get data
Insert(alert)
E-Call Server
Crash


Informations utilisateur
Nom: POMPIER LURE
Prénom: VSAV1
Téléphone: 0384304385
Type alerte: Accident avere
Détails utilisateur
Plan
Satellite
Mixte
Colmar
Mulhouse
Belfort
Basel
Montbéliard
Lure
Vesoul
Gray
Google

Outline

- Societal and technological progresses have brought a widespread diffusion of computer services characterized by an ever increasing complexity, pervasiveness, and social meaning .
- These novel forms of social services and social organization constitute a promise of new solutions against the many new problems our societies are experiencing.
- The current organizations are proving to be ineffective and unable to scale to the sizes of our new "big world".
- Engineering the design of novel forms of collective adaptive services will make us able to turn the very same size of society into a source of valuable resources.
- The exploitation of such resources requires the introduction of novel and smarter social organizations and principles, such as those based on a "self-serve society" [14,15].

Thank you for your attention.

References I

1 D. Miorandi, F. De Pellegrini, O. Mayora, R. Giaffreda, *Collective Adaptive Systems: Scenarios, Approaches and Challenges*, ftp://ftp.cordis.europa.eu/pub/fp7/ict/docs/fet-proactive/shapefetip- cas10 en.pdf.

2 S. Kernbach, T. Schmick, J. Timmis, *Collective Adaptive Systems: Challenges Beyond Evolvability*, http://arxiv.org/abs/1108.564, 2011.

3 S. Kernbach (ed). *Handbook of Collective Robotics: Fundamentals and Challenges*. Pan Stanford Publishing, 2011.

4 Y. Brun et al., *Engineering Self-Adaptive Systems through Feedback Loops*, Software Engineering for Self-Adaptive Systems, LNCS Hot Topics, Vol 5525, pp. 48-70, 2009.

5 J. O. Kephart and D. M. Chess. *The Vision of Autonomic Computing. Computer*, 36(1):41-50, 2003

6 J. Gaber, *Action Selection Algorithms for Autonomous System in Pervasive Environment: A Computational Approach*. TAAS 6(1): 10, 2011.

7 B. Cheng et al., *Software Engineering for Self-Adaptive Systems: A Research Roadmap*, LNCS 5525, pp. 1-26, 2009.

References II

8 M. Bakhouya, R. Campbell, A. Coronato, G. De Pietro, A. Ranganathan, *Introduction to special section on formal methods in pervasive computing*, ACM Transactions on Autonomous and Adaptive Systems (TAAS) 7: 1. 6, 2012.

9 W. Ait-Cheik-Bihi, A. Nait-Sidi-Moh, M. Bakhouya, J. Gaber, M. Wack, *TransportML platform for collaborative Location-based services*, Service Oriented Computing and Applications, 6:4, 363-378, 2012.

10 S. Cai, M. Becherif, M. Bakhouya, M. Wack, *Context Aware Embedded System for Intelligent Vehicles and Smart Roads*, ACM International Conference on Pervasive Services (ICPS'2010), 1-6, 2010.

11 M. Bakhouya, J. Gaber, P. Lorenz, *An Adaptive Approach for Information Dissemination in Vehicular Ad hoc Networks*, Network and Computer Applications, Elsevier 34: 6. 1971-1978, 2011.

12 K. Dar, M. Bakhouya, J. Gaber, M. Wack, P. Lorenz, *Wireless Communication Technologies for ITS Applications*, IEEE Communications Magazine 48: 5. 156-162, 2010.

References III

13 M. Bakhouya, J. Gaber, *A Query Routing Approach based on Users' Satisfaction for Resource Discovery in Service-Oriented Networks*, World Wide Web, Springer 13: 1-2. 61-73, 2010.

14 M. Bakhouya, J. Gaber, *Approaches for Ubiquitous Computing*, Wireless Ad hoc and Sensor networks Edited by:H. Labiod. 111-142 London, UK: ISTE Publishing Knowledge / John Wiley and Sons Inc, 2008

14 A. Coronato and V. De Florio and M. Bakhouya and G. Di Marzo Serugendo, *Formal Modeling of Socio-technical Collective Adaptive Systems*, ASENSIS 2012, SASO conference, Lyon, France, 2012.

15 V. De Florio and A. Coronato and M. Bakhouya and G. Di Marzo Serugendo, *Service-oriented Communities: Models and Concepts towards Fractal Social Organizations*, SITIS 2012, Sorrento-Naples, Italy, 2012.

16 C. Heinzemann, *Modeling Behavior of Self-Adaptive Systems*, http://ebookbrowse.com/modeling-behavior-of-self-adaptive-systems5-ppt-d217019628, 2012.

17 http://www.safespot-eu.org/

References IV

18 http://cordis.europa.eu/fp7/ict/fet-proactive/

19 M. Leucker and C. Schallhart, *A brief account of runtime verification*, J. Log. Algebr. Program., 78:5, pp. 293-303, 2009.

20 K. Ogata, *System Dynamics*, ISBN 0131424629, Prentice-Hall, 4th Ed, 2004.

21 A. Borshchev and A. Filippov, *From System Dynamics and Discrete Event to Practical Agent Based Modeling: Reasons, Techniques, Tools*, The 22nd International Conference of the System Dynamics Society, pp. 1-23, 2004.

22 http://www.project-asset.com/