Advanced hybrid satellite and terrestrial system architecture for emergency mobile communications

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1st phase of Ph.D. research on

"Ad hoc mobility in satellite-based networks for security applications"

Overview

- **Introduction**
- **Overview on emergency phases and requirements for disaster management**
- **Hybrid system architecture for emergency mobile communications:**
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  - Mobile ad-hoc mesh network
- **Conclusions**
- **Future work**
- **Main achievements**
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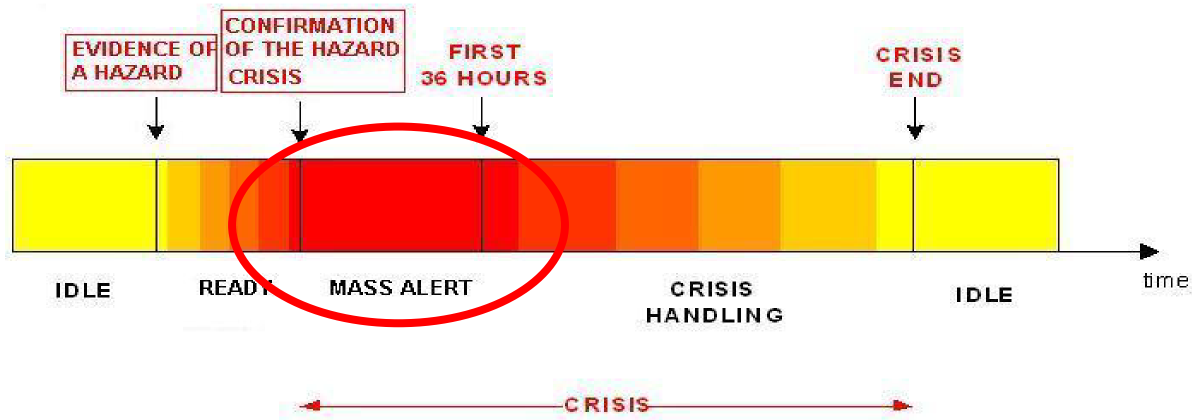
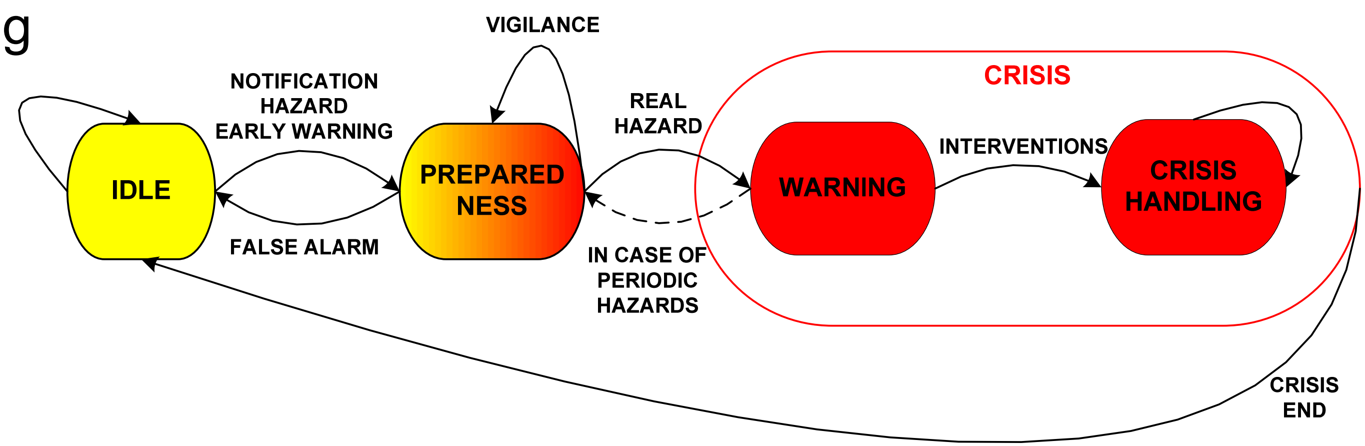
Overview on emergency phases and requirements for disaster management

Emergency phases for disaster management

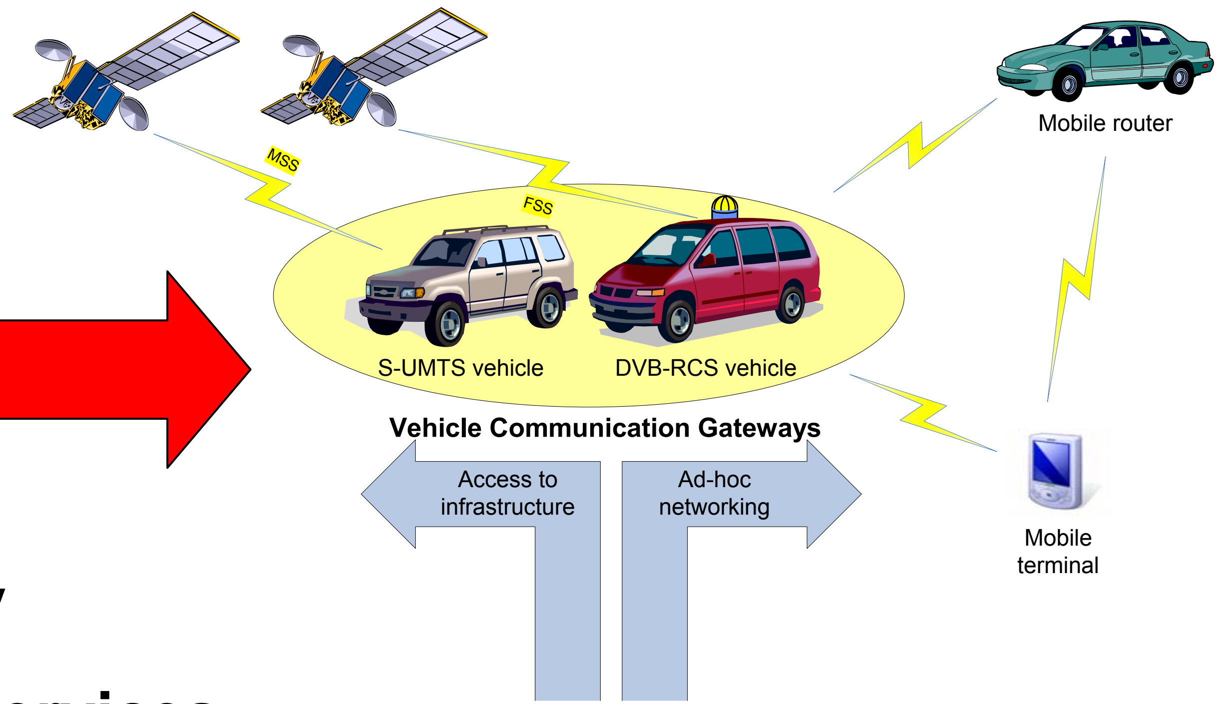
- **Preparedness:**
  - Observation
  - Maintenance of the system
  - Education
- **Crisis**
  - Warning
  - Crisis handling
- **Post-crisis**





Emergency requirements

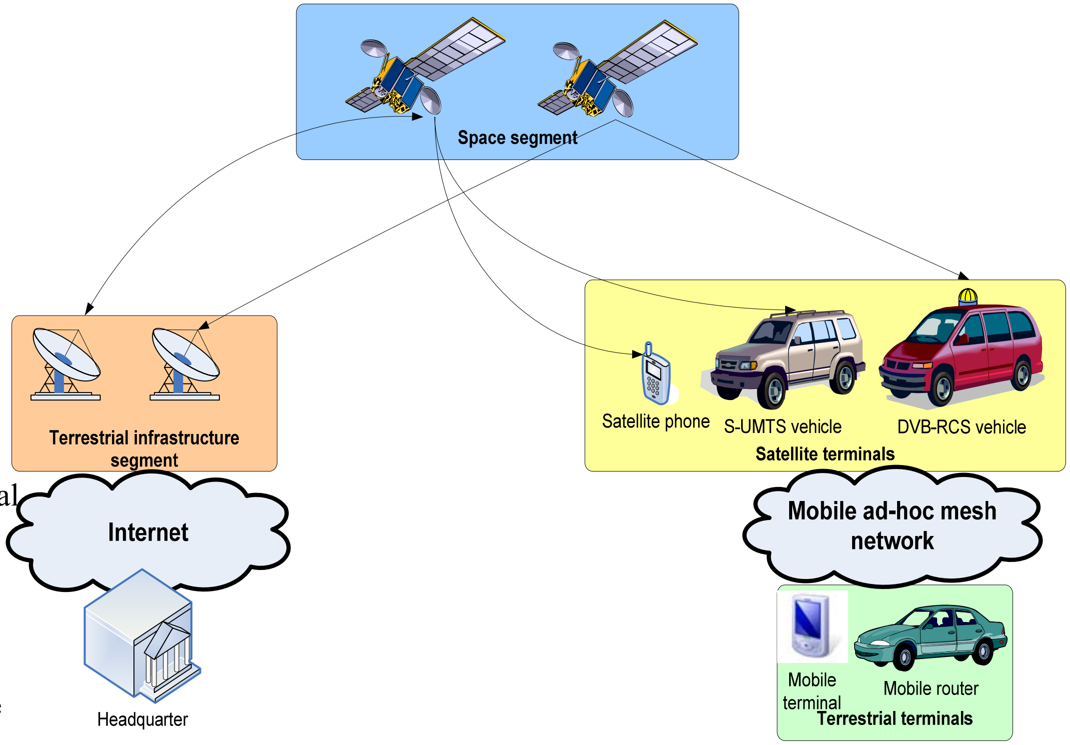
- **Mobility**
- **Reliability**
- **Scalability**
- **Interoperability**
- **Interdependency**
- **Voice and data services support**



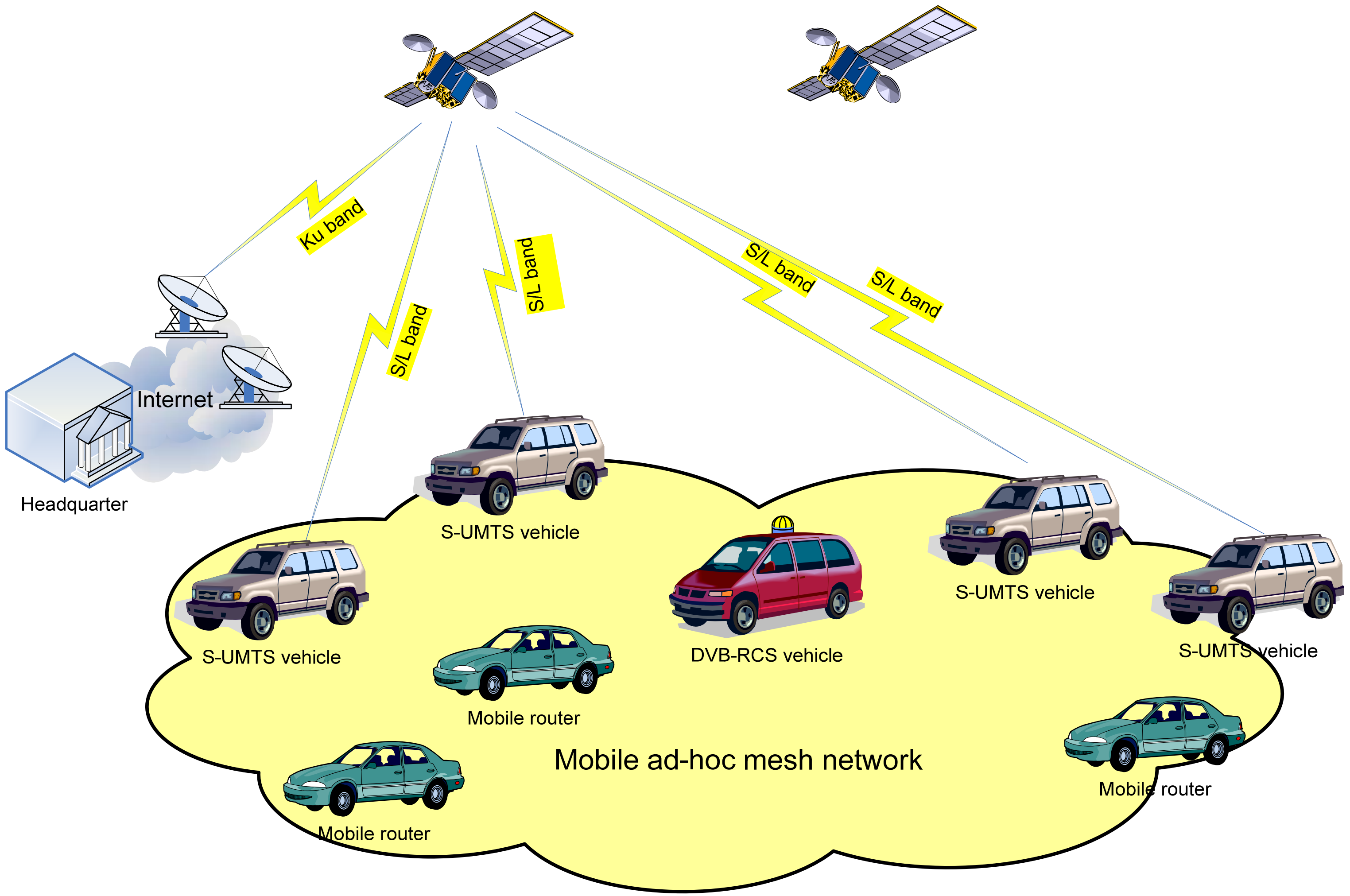
Hybrid system architecture for emergency mobile communications

General overview of the proposed IPv6-based system architecture

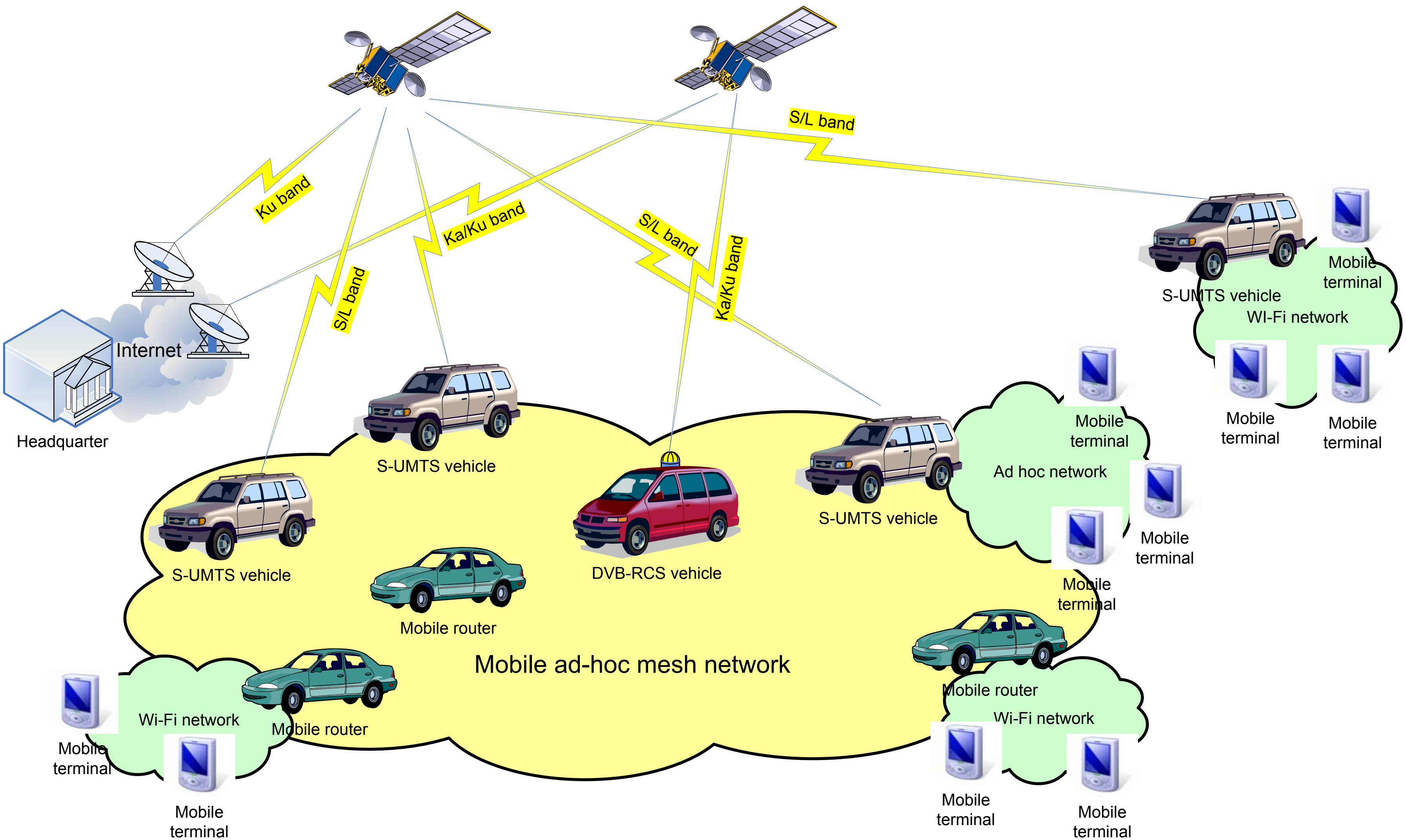
- A space segment which includes two GEO satellites, one MSS and one FSS;
- A terrestrial infrastructure segment which includes two Earth stations connected through the Internet to the headquarter, providing the link between the satellite system and satellite terminal segment deployed in the disaster site;
- A terminal segment which includes:
  - A satellite terminal segment composed of:
    - User terminals such as satellite phones that provide direct satellite access to end-users;
    - VCGs that provide satellite access to terrestrial user terminals and mobile routers;
  - A terrestrial terminal segment that includes:
    - End-user terminals such as handhelds, PDAs, PCs;
    - Vehicular terminals that provide access to the terrestrial end-user terminals and are enabled with routing capabilities, they form a mobile ad-hoc mesh network over the crisis area.



Overall hybrid satellite-terrestrial system architecture – Network Deployment Phase 1



Overall hybrid satellite-terrestrial system architecture – Network Deployment Phase 2

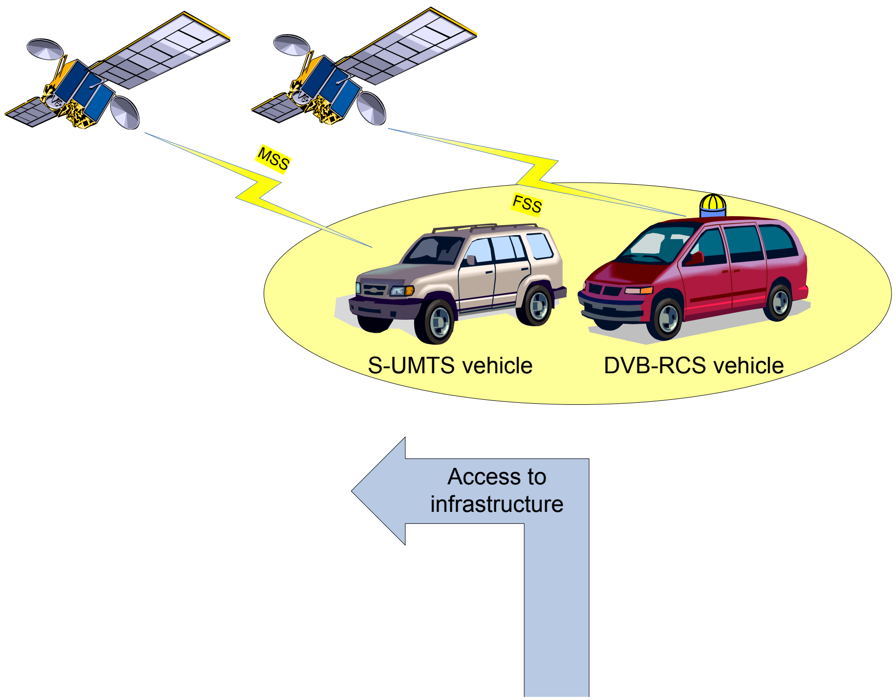


Hybrid satellite-terrestrial system architecture features

- **The presented system architecture combines the advantages of:**
  - IPv6-based networks:
    - Mobility support, neighbor discovery, address configuration, multicast, security.
  - Satellite systems:
    - Mobility and multimedia services provisioning.
    - Robustness, reliability and availability.
    - Access from any location and quickly deployable.
    - Local, regional and international connectivity.
    - Less vulnerability to natural or human aggressions.
  - Mobile Ad-hoc Mesh Networks:
    - Large coverage due to multi-hop forwarding
    - High bandwidth due to short hops.
    - Automatic neighbor node detection, establishment and maintenance of network connectivity in an ad-hoc fashion.
    - Self-configuring nature allows easy and rapid deployment with low cost backhaul.
    - Dynamically adapt to changing environments and essentially self-heal in case of node and link failures.

Satellite links

- **Two types of VCGs:**
  - S-UMTS vehicles allow:
    - High mobility
    - Low cost antennas and terminals
    - To provide external connectivity to terminals not reached by the ad-hoc mesh network
  - DVB-RCS vehicles permit:
    - High throughput
    - Efficient bandwidth utilization
    - Cheap capacity
    - VSAT antennas
    - To provide multimedia data and services



S-UMTS vehicles' specifications

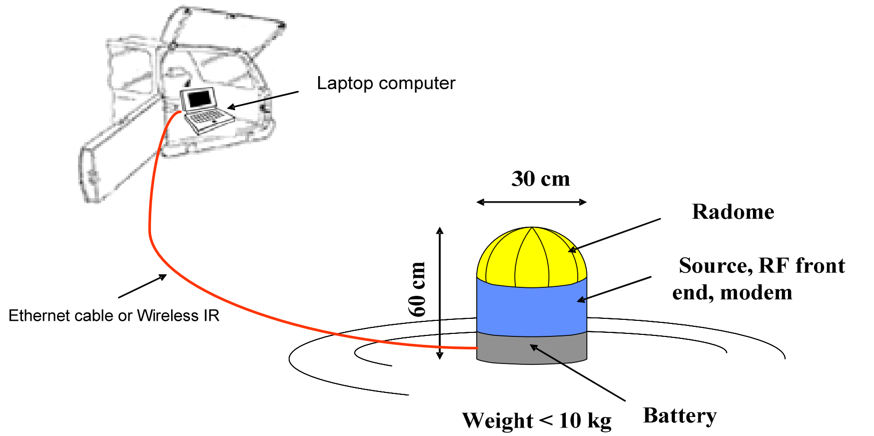
- **Two types of satellite antennas have been proposed:**
  - **Active antenna**
  - **Omnidirectional antenna**
- **Terminal mobility is considered around 50 km/h.**
- **Considering the limited achievable data rate with both antennas, the idea is to dynamically create a distributed gateway between S-UMTS vehicles in order to increase MSS capacity.**
  - For instance, 5 vehicles with active antennas may provide an aggregate uplink capacity of 400 Kbit/s.

Category	Parameters	Active antenna	Omnidirectional antenna
RF Section Characteristics	Frequency Band	2.1-2.2 GHz	
	Antenna Diameter	0.16 m	0.09 m
	Rx G/T	- 16 dB/K	- 21 dB/K
	Tx EIRP	18.5 dBW	10.5 dBW
	Total Bandwidth	Tx: 5 MHz Rx: 5 MHz	
Downlink	Proposed Air Interface	DVB-S2 CCM	
	Modulation and Coding	QPSK 1/2	
	Access	TDM	
	Max data rate	4Mbit/s	
Uplink	Proposed Air Interface	S-UMTS	
	Modulation and Coding	QPSK 1/3	
	Access	CDMA	
	Spreading factor	32	64
	Max data rate per user	80 Kbit/s	40 Kbit/s

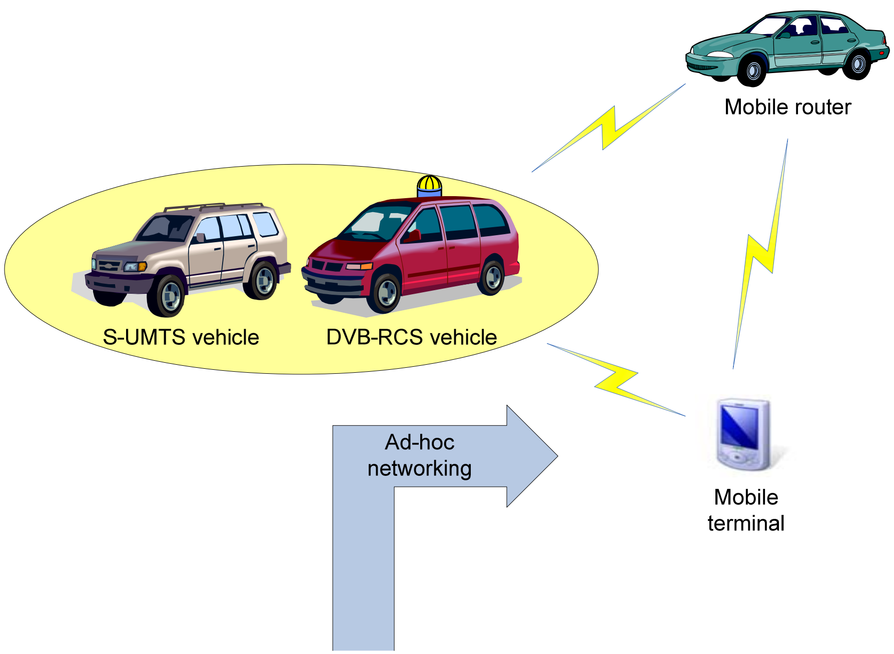
DVB-RCS vehicles' specifications

Category	Parameters	Rain conditions	Clear sky conditions
RF Section Characteristics	Frequency Band	20.2-30 GHz	
	Antenna Diameter	0.3 m	
	Rx G/T	8 dB/K	
	Tx EIRP	38 dBW	
	Total Bandwidth	Tx: 56 MHz Rx: 56 MHz	
Downlink	Proposed Air Interface	DVB-S2	
	Modulation and Coding	QPSK 1/4	QPSK 1/2
	Access	TDM	
	Max data rate	8 Mbit/s	25 Mbit/s
Uplink	Proposed Air Interface	DVB-RCS	
	Modulation and Coding	QPSK 1/2	
	Access	MF-SDMA	
	Max data rate	128 Kbit/s	512 Kbit/s

- Part of Thales Alenia Space project (ESSENCE).
- With a diameter of 30 cm and a satellite EIRP of 58 dBW, the presented DVB-RCS vehicle can receive, on the satellite downlink, data rates up to 25 Mbit/sec in temperate and desert zones and a data rate of 8 Mbit/sec in tropical zone.
- With a satellite G/T of 19dB/K thanks to the Space Division Multiple Access (SDMA), it can provide uplink with a data rate up to 512kbit/sec in temperate and desert zones and a data rate of 128 kbit/sec in tropical zone.
- The terminal mobility spans from fixed to a target speed of 10 Km/h.



Mobile ad-hoc mesh network – Network topology



- **Two types of vehicles:**
  - VCGs enabled with routing and gateway functionalities
  - Vehicular terminal with routing capabilities
- **Network topology configuration:**
  - Each vehicle is a Mesh Point (MP), it establishes peer links with MP neighbors and is fully participant in the mobile ad-hoc mesh network.
  - Each vehicle can assume the functionality of Mesh Access Point (MAP), proving to mobile terminals access to the mesh network.
  - VCGs are also Mesh Portal Points (MPPs), as they represent MPs through which is possible to enter and exit the ad-hoc mesh network.

Mobile ad-hoc mesh network - 802.11s

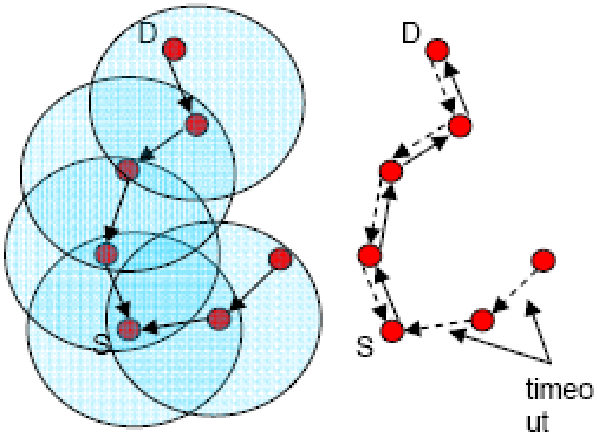
- **802.11s is the most relevant emerging standard for Wireless Mesh Network (WMN) technology in the context of public safety and disaster recovery communications.**
- **802.11s is an amendment being developed to the IEEE 802.11 WLAN standard in order to integrate mesh networking services and protocols with 802.11 at MAC layer.**
- **802.11s is proposed for the mobile ad-hoc mesh network as:**
  - It creates a Wireless Distribution System (WDS) with automatic topology learning and wireless path configuration.
  - It allows dynamic, *radio-aware* path selection in the mesh, enabling data delivery on single-hop and multi-hop paths (unicast and broadcast/multicast).
  - Extensible to allow support for diverse applications and future innovation.
- **It allows to create a multi-hop decentralized and distributed network, able to dynamically self-organize and self-configure.**

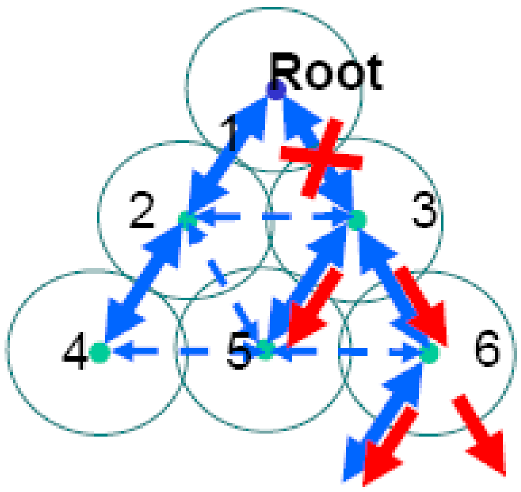
Mobile ad-hoc mesh network

- **802.11s proposes as default path discovery protocol the Hybrid Wireless Mesh Protocol that:**
  - Combines the flexibility of on-demand route discovery with efficient proactive routing to a mesh portal:
    - On demand routing offers great flexibility in changing environments
    - Pro-active tree based routing is very efficient in fixed mesh deployments
    - The combination makes it suitable for implementation on a variety of different scenario configurations
  - Use simple mandatory metric based on airtime as default, with support for other metrics:
    - Extensibility framework allows any path selection metric (QoS, load balancing, power-aware, etc)

Hybrid Wireless Mesh Protocol

- **On demand routing is based on Radio Metric Ad hoc On-demand Distance Vector (RM-AODV):**
  - Based on basic mandatory features of AODV (RFC 3561)
  - Extension to identify best-metric path
  - Destinations nodes inside the ad hoc mesh network discovered on-demand

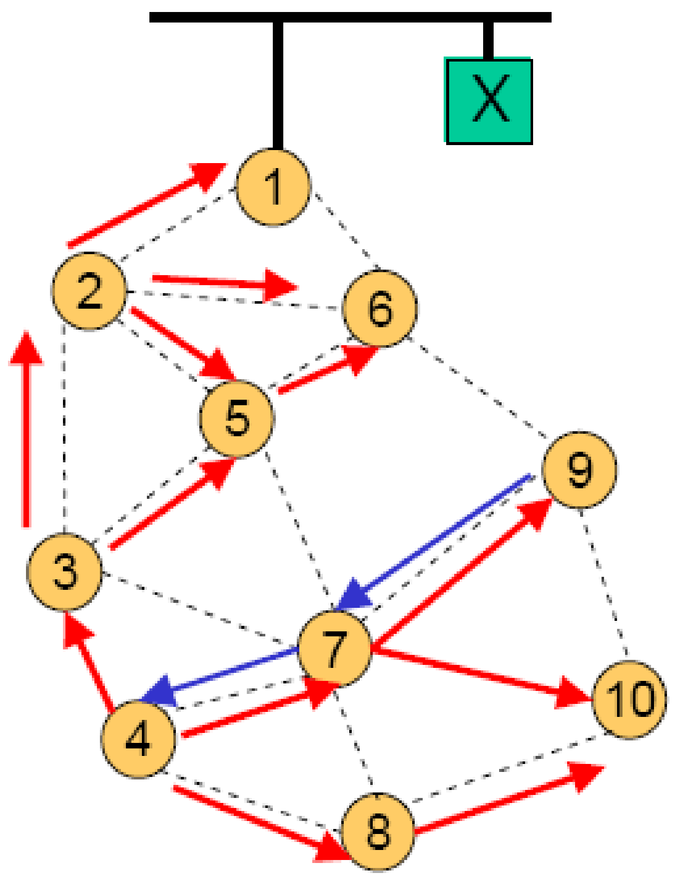




- **Pro-active routing is based on tree based routing:**
  - If a Root portal is present, a distance vector routing tree is built and maintained
  - Tree based routing is efficient for hierarchical networks
  - Tree based routing avoids unnecessary discovery flooding during discovery and recovery

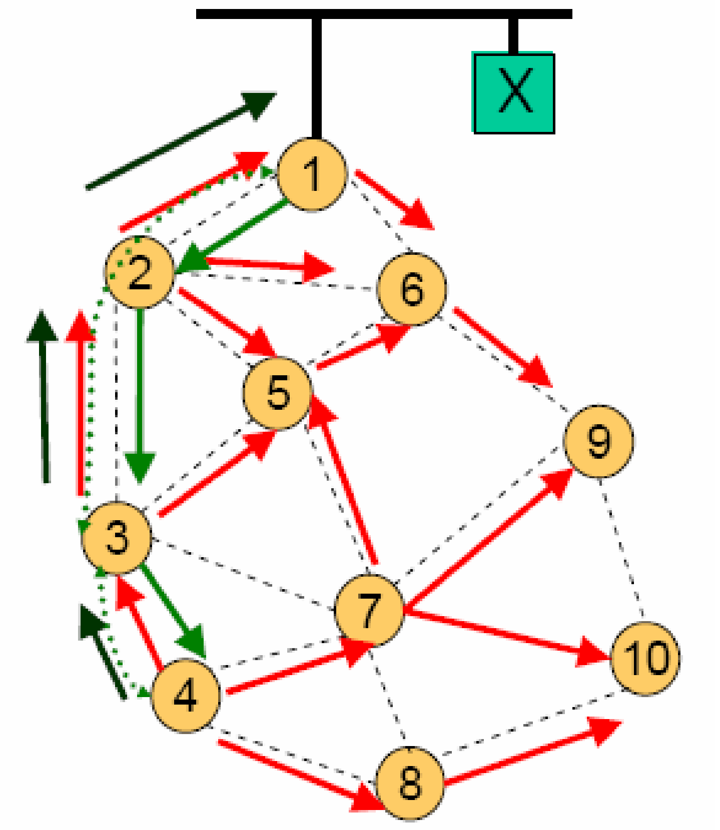
HWMP Example #1

- **No Root, Destination Inside the Mesh:**
  - **MP 4 wants to communicate with MP 9:**
    1. MP 4 first checks its local forwarding table for an active forwarding entry to MP 9
    2. If no active path exists, MP 4 sends a broadcast RREQ to discover the best path to MP 9
    3. MP 9 replies to the RREQ with a unicast RREP to establish a bi-directional path for data forwarding
    4. MP 4 begins data communication with MP 9



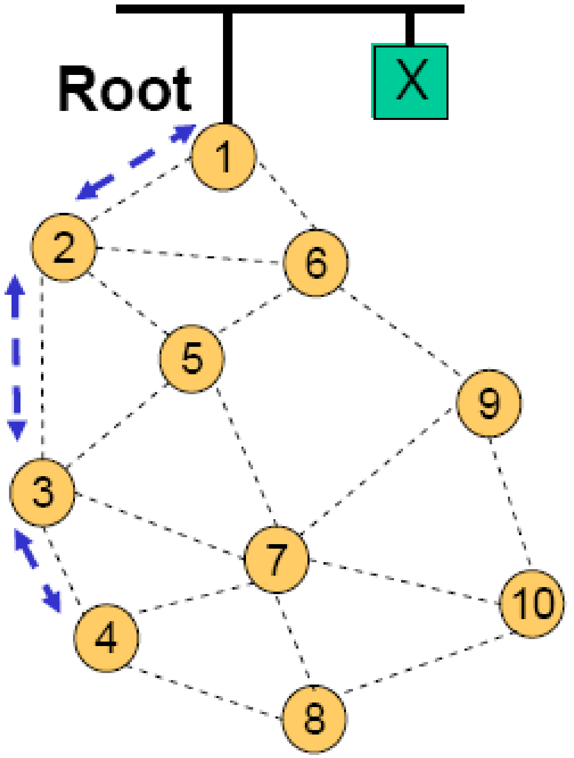
HWMP Example #2

- **Non-Root Portal(s), Destination Outside the Mesh**
  - **MP 4 wants to communicate with X:**
    1. MP 4 first checks its local forwarding table for an active forwarding entry to X
    2. If no active path exists, MP 4 sends a broadcast RREQ to discover the best path to X
    3. When no RREP received, MP 4 assumes X is outside the mesh and sends messages destined to X to Mesh Portal(s) for interworking
       - A Mesh Portal that knows X may respond with a unicast RREP
    4. Mesh Portal MP 1 ` LAN segments according to locally implemented interworking



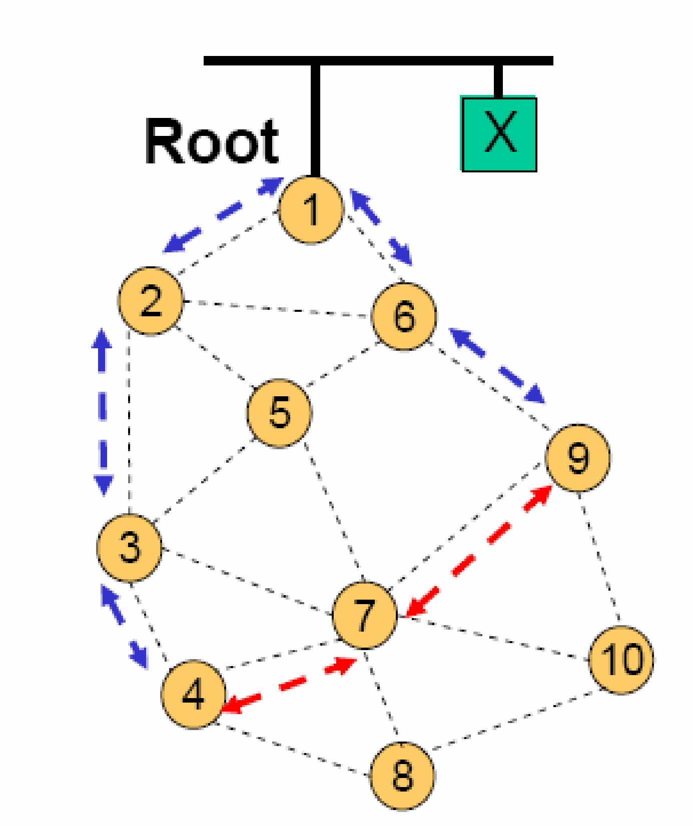
HWMP Example #3

- **Root Portal, Destination Outside the Mesh**
  - **MP 4 wants to communicate with X**
    1. MPs learns Root MP 1 through Root Announcement messages
    2. If MP 4 has no entry for X in its local forwarding table, MP 4 may immediately forward the message on the proactive path toward the Root MP 1
    3. When MP 1 receives the message, if it does not have an active forwarding entry to X it may assume the destination is outside the mesh
    4. Mesh Portal MP 1 forwards messages to other LAN segments according to locally implemented interworking



HWMP Example #4

- **With Root, Destination Inside the Mesh**
  - **MP 4 wants to communicate with MP 9:**
    1. MPs learns Root MP 1 through Root Announcement messages
    2. MP 4 first checks its local forwarding table for an active forwarding entry to MP 9
    3. If no active path exists, MP 4 *may* immediately forward the message on the proactive path toward the Root MP 1
    4. When MP 1 receives the message, it flags the message as “intra-mesh” and forwards on the proactive path to MP 9
    5. MP 9, receiving the message, *may* issue a RREQ back to MP 4 to establish a path that is more efficient than the path via Root MP 1



Conclusions

- **A new IPv6-based system architecture, which integrates satellite and wireless terrestrial networks to provide emergency mobile communications, has been designed.**
- **It is based on VCGs, which have double fuctionalities:**
  - They provide backhaul connection to the disaster site through satellite links. Making use of the two types of VCGs – S-UMTS vehicles and DVB-RCS vehicles – permits to beneficiate of narrowband and broadband advantages and to create a universal scenario suitable for most of emergency mobile communications needs.
  - They create a mobile ad-hoc mesh network, together with terrestrial terminals, which is a multi-hop wireless network with self-healing and self-configuring capabilities.

Future work

- **Investigation is needed on mobility issues as:**
  - Routing mechanisms for internal and external traffic, taking into account instantaneous link conditions and available capacity.
  - Dynamic access to the ad-hoc mesh network for MPs and mobile terminals.
  - Handover mechanisms for micro and macro-mobility.
  - Traffic capture in the ad-hoc mesh network.
  - Connection continuity mechanisms for voice and multimedia communications.

Main Achievements

- G. Iapichino, C. Bonnet, O. del Rio, C. Baudoin, I. Buret, “Advanced hybrid satellite and terrestrial system architecture for emergency mobile communications”, accepted to 26th AIAA ICSSC, San Diego, California, June 2008.
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Thanks for your attention