Vehicular networks

MANETs (Mobile Ad hoc NETworks) were developed within IETF to extend the traditional Internet to mobile networks: indeed the peculiar feature of mobile network is mobility which implies that topologies are arbitrary and changing in time. With respect to traditional wired network, MANETs nodes and routers are connected with wireless links, therefore the medium channel has different characteristics to keep in mind as the error probability much more high.

The network organization can be both pure ad hoc or with some infrastructure: typically nodes implement at MAC layer 802.11, but for VANETs (stations are vehicular) it is possible have different solutions. With respect to MANETs, VANETs are characterized by:

. a much more higher mobility in terms of speed: indeed MANETs nodes can be people moving;

. due to the previous fact, the topology is much more dynamic;

. a much flexible usage of resources: they are not limited in energy consumption, memory and capabilities;

. since stations can be equipped with a satellite positioning system (GPS) they are synchronized to a common reference and their geographical position is known (useful for geocast communications).

Services and applications

VANETs can be used for:

. road safety;

. traffic control;

. entertainment (for multimedia streaming use the cooperative approach).

Some application are activate by events while others have to run everytime and others are activated just periodically; for example:

. car accident notification: application event based;

. road and traffic conditions, parking availability: applications even periodic or event based;

. commercial applications are typically run everytime.

Architecture

ITS (Intelligent Transportation System) are all efforts applied to infrastructure and vehicles to add information and communication technology; this goal takes also care of the environment, therefore technologies tries to reduce this impact. Major components are:

. vehicles and user applications;

. infrastructures (to monitor and control);

. network that allows communications.

Vehicles are equipped with *On Board Unit*, OBU, while the infrastructure is composed by *Road Side Unit*, RSU; both of them have a satellite positioning system. Available communications are:

. vehicle to vehicle: V2V;

. infrastructure to vehicle: I2V;

. vehicle to infrastructure: V2I.

In a V2V scenario is not known when it is possible to meet another vehicle to which the communication is feasible: this kind of context is suitable for vehicle collision avoidance because allows to react quickly since no infrastructure is needed. Due to this fact, communications happen with a lower cost.

In the other scenario, V2I, moments in which is possible to communicate are known a priori: indeed RSU are placed at a fixed distance each of them. Therefore, the main difference between V2V and V2I is the coverage area. V2I communications are typically short because OBU have very fast movements and due to the fact that data rates are high. Of course, if a communication take place for a large time, handover procedure is provided to not cut off the call. This kind of scenario is suitable for downloads.

802.11p

The standardization started in 2002 with the name Dedicated Short Range Communication (DSCR) and in 2003 moves to IEEE forum with the name 802.11p, also called Wireless Access Vehicular Environment (WAVE). The standard is needed because:

. the operation range is much more long with respect to 802.11 (up to 1 km);

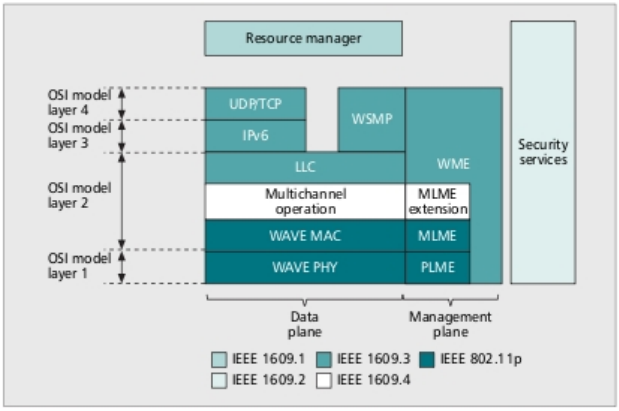
. high speed of nodes implies short-connectivity time;

. high presence of multipath (relative to the environment: urban or rural);

. presence of many ad-hoc networks overlapped;

. automotive application to be supported (reliable multicast).

The following picture shows the protocol stack:



Security is a very important issue: function like authentication and privacy are provided.

Physical layer

The 802.11p physical layer is based on 802.11a physical layer, therefore uses OFDM; the frequency band used is 5.9 GHz with seven channels of 10 MHz each one. One channel is voted to high priority traffic (signalling for example): it is called CCH (Control Channel); the other 6 channels are used for low priority data (entertainment purpose for example): called SCH (Service Channels) they can be aggregate, in pairs, like 802.11a, to achieve an higher throughput; of course, this implies that robustness against fading is reduced. Available data rates are between 3 Mbit/s, which is also the basic rate, up to 27 Mbit/s: as it is possible to see the basic rate is much more higher than the basic rate of 802.11a. Moreover, all parameters times are almost doubled: those choices have been taken to deal with ISI due to multipath and Doppler effect.

Communication ranges are different considering the environment: in a rural scenario with low vehicle density, typically the transmission power is increase reaching higher distances, while in an urban scenario the range is reduced due to high density. Typical values are: 250-500 m.

MAC layer

Based on previous 802.11 MAC standards, the 802.11p MAC uses CSMA-CA and implements some features of 802.11e MAC standard. Main characteristics are:

. channel coordination;

. Wave Basic Service Set (WBSS);

. Enhanced Distributed Channel Access (EDCA).

Channel Coordination It describe the way in which frequencies are actually used: each sync interval is fixed at 100 ms composed by:

. 50 ms for CCH;

. 50 ms for SCH.

Therefore, with a download data rate of 27 Mbit/s it is just possible achieve 13 Mbit/s because it is used half of a period.

Guard intervals are needed to deal with possible sync errors and they are dimensioned based on the channel switching time, usually fixed at 4 ms.

Node synchronization is provided through GPS: in this way the UTC (Universal Time Coordination) is received every second with a small error (smaller than 100 ns). UTC is used to define CCH and SCH intervals and, if a node is not able to hear this signal, it can only monitor the CCH to listen safety messages. However synchronization is always ensure because, packets have a field to specify the time reference, therefore station not able to detect UTC can be synchronized indirectly by receiving packets.

Some issues are:

. high priority messages, sent through CCH, may suffer of relevant delays;

. bandwidth inefficiency: when the CCH is monitored, 6 SCH can not be used;

. transmission on SCH have to be interrupted frequently (period equally divided) to monitor CCH.

WBSS WBSS is a group of nodes that operates according to WAVE specifications: similar to IEEE 802.11 BSS with infrastructure, but in this scenario authentication and association features are provided. Components are:

- WBSS provider: it can be both OBU or RSU and his MAC is called BSSID; he is in charge of initiate the WBSS by transmitting a WSA (WAVE Service Advertisement) frame on the CCH: this frame is not necessary sent periodically due to possible short connectivity; parameters specified by WSA are:
  - WBSS existence;
  - parameters to join WBSS;
  - services provided and on which SCH are provided;
- WBSS user: it can be, again, both OBU or RSU and are nodes that join the WBSS after having received a WSA.

A given node can be either provider or user, but if he is an user it can belong to a WBSS at a time by selecting the one that offer services with highest priority, in the case in which he is covered by more than one WBSS. Moreover, nodes can change their role dynamically.

Frames transmitted can be distinguished based on the priority:

- management frames sent on CCH called Wave Announcement Frames;
- data frames:
  - IP data frames only on SCH;
  - Wave Short Message Protocol frames either on CCH or SCH.

Wave Short Message Protocol frames were designed exactly for highly dynamic conditions exchange of messages: they are short because they include few information like the vehicle's position, the speed, the acceleration and the movement direction. This mobility profile is important to be known by other vehicles to configure their physical layer in the proper way such that a reliable communication is guaranteed.

The MAC layer architecture is similar to 802.11e and operates with two entities: one for CCH and one for SCH.

Issues: 1 Since safety messages require low latency and reliability 802.11e, although provide QoS, is not suitable to delivery them because:

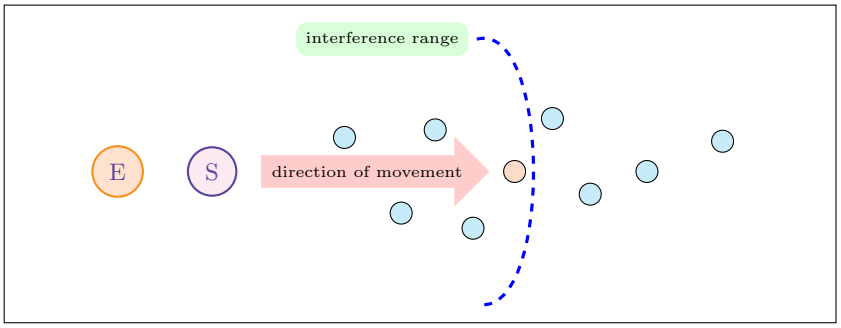
- CSMA-CA implies unpredictable delay in accessing the channel (this fact is really evident in high load conditions);
- the collision probability increases with the number of MAC cards contending the channel.

A feasible solution is adopting TDMA approach that, although is difficult to implement, it is possible to implement due to common reference obtained by GPS.

Issues: 2 Point to point communication can use RTS/CTS, but in multicast or geocast scenarios transmissions become unreliable. Several solution can be adopted:

. replication avoidance: by checking the packet ID, stations can not re-broadcast it if they have already seen it;

. position-based:



looking at the picture, when an event E occurs, the nearest node behaves like a source that notify such an event; there are two ways to notify it:

- a *centralized method* for which the source elects one forwarder chosen the far as possible (to improve at maximum the spatial advance) from his current position; this is possible thanks to the knowledge of positions given by WSMP frames;
- a *distributed method* for which the election of the forwarder is made by every node: the decision happens by extracting a random time, larger if the node is close to the source; in this way the shortest time is probably select very far from the source obtaining the same performances of the centralized approach;

it is possible that, the farthest node from the source expire a low SNR: in this case it is better elect another forwarder, much more close to the source;

. cluster-based: nodes are grouped in clusters and only cluster-heads are in charge of re-broadcast packets; of course creation and maintenance of clusters implies a relevant overhead;

. probability-based: transmissions are delayed randomly to avoid collisions;

. processing-based: data aggregation/fusion; the drawback is the time needed to perform those operations.