COURSE 12
WIRELESS HETEROGENEOUS NETWORKS

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CONTENT

- Introduction
- Network interoperability
- Wireless heterogeneous network architectures
- Vertical handover
- Network selection
- Standardized network architectures

INTRODUCTION

- Organizing multimodal transportation requires a tight coupling between different transportation systems through centralized databases
  - This would help to provide travelers with up-to-date information helping them to reduce the trip time and the energy consumption
- It became critical to provide in vehicle applications with fully operational Internet connectivity
- The Car-to-Car Consortium has identified more than 300 applications that could use Internet connectivity:
  - “Traditional” ITS related applications: vehicle tracking and traffic assessment
  - New applications related to infotainment and driver assistance
- ITS related services rely on information and communication technologies

INTRODUCTION

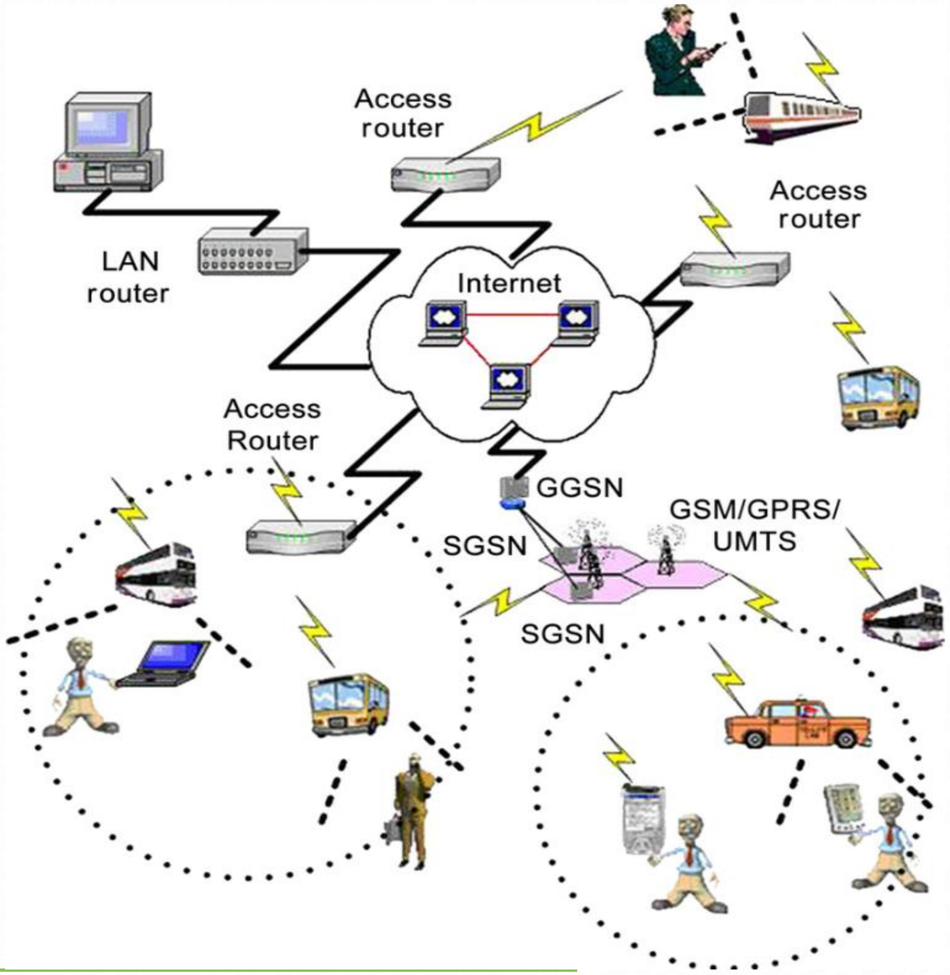
- Efficient cooperation is required between various components involved in providing the service: mobile stations/terminals, roadside units, central systems or databases, small electronic devices (sensors, controllers)
- To make all these services possible while on move it is necessary continuous Internet connectivity at a reasonably high data rate and at reasonable cost
  - There are no available communication technologies that fulfill the requirements in terms of performance, cost, response time, availability and reliability (5G not included)
  - The use of heterogeneous wireless networks such as 3G/4G, WLAN, WWAN can satisfy the variety of emerging applications that require different levels of QoS
    - The complementary nature of these technologies makes their diversity suitable to enhance the overall capacity and coverage
    - Heterogeneous networks can provide better performance than any single technology and can offer different levels of QoS and radio characteristics

INTRODUCTION

- Heterogeneous network connect devices with different operating systems and/or protocols
- Heterogeneous wireless networks (HWN) connect devices with different radio access technologies (WiFi, WiMAX, GSM, 3G, 4G, 5G, IEEE 802.11p, etc.)
  - They represent a ”multi-x” domain:
    - Multi-technology
    - Multi-domain
    - Multi-spectrum
    - Multi-operator
    - Multi-manufacturer
  - They can offer ABC services – Always the Best Connectivity

INTRODUCTION

- The most important characteristics of HWN are:
  - Network selection
  - Overall network capacity determination
  - Radio access technology interoperability
  - Handover
  - Mobility
  - QoS
  - Interference between radio access technologies



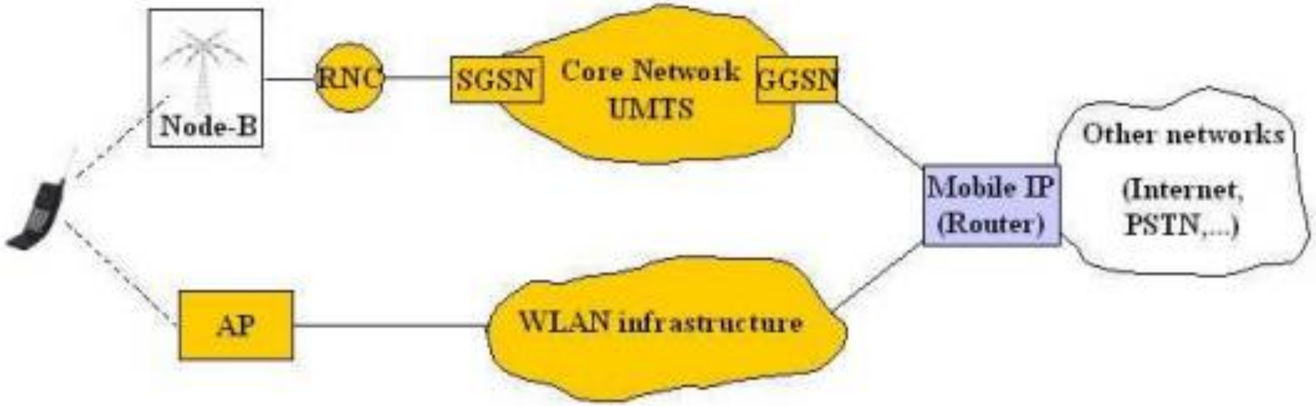
INTEROPERABILITY LEVELS

- 3GPP defines 6 interoperability levels for HWN:
  - Level 1: Common billing and customer support
    - The user pays one single bill for mobile data and WLAN
    - It is based on a commercial agreement between operators
    - The systems offer the services independently
  - Level 2: Common access control
    - WLAN offers the same security as mobile networks
    - The user uses the same interface to connect to both systems
  - Level 3: Packet-switching based access to all services
    - There is no handover
    - Different technologies offer the same services, QoS is handled also by WLAN

INTEROPERABILITY LEVELS

- Level 4: Service continuity
  - Handover is implemented
  - The user can experience service interruptions (during handover)
- Level 5: Continuous mobility
  - The users cannot sense the difference between the systems, not even during handover
  - WLAN does not offer access to circuit-switch based services
- Level 6: Access to circuit-switched services
  - WLAN supports also circuit-switch based services

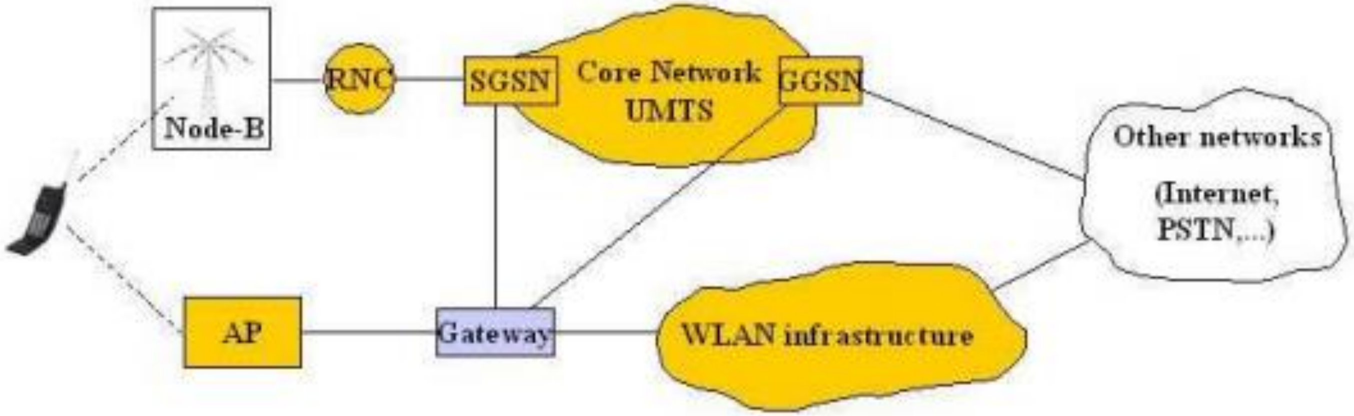
NETWORK ARCHITECTURES



- Loose coupling
  - The networks are separated
  - Mobile-IP is implemented
    - The user is connected to the home agent server
    - If the user connects to another server (foreign agent), the two servers communicate with each other
    - The messages dedicated to the user are sent to the home agent which redirects them to the foreign agent
    - The network is relatively easy to implement, almost no cooperation between providers is necessary
    - Real-time services can be affected during handover due to the delays introduced by mobile IP

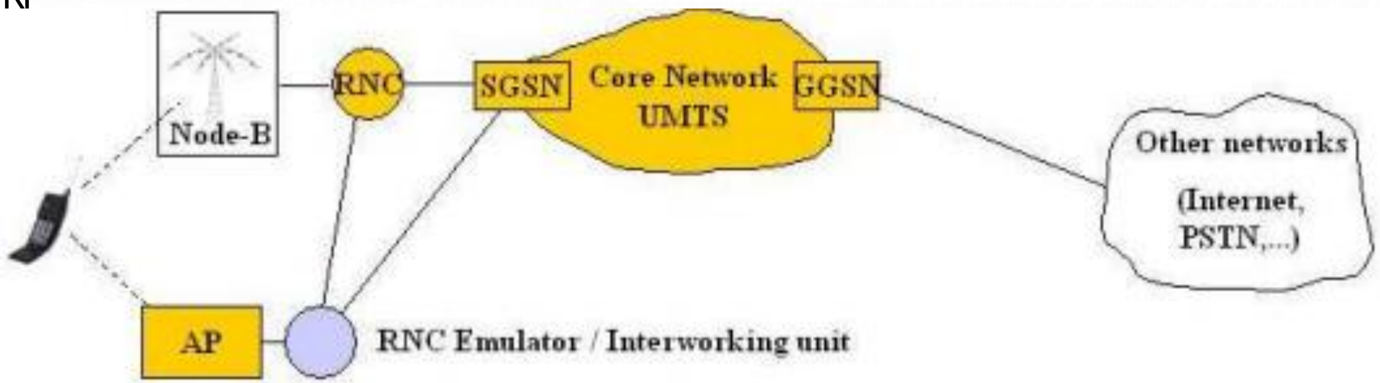
NETWORK ARCHITECTURES

- Gateway
  - A gateway, which connects WLAN to SGSN (Serving GPRS Support Node) and GGSN (Gateway GPRS Support Node), is introduced
    - The link to SGSN is used when a WLAN user is in roaming in mobile networks
    - The link to GGSN is used when a mobile network user is in roaming in WLAN
  - The handover is faster
  - The providers must cooperate
  - The connection between equipment is necessary
  - The implementation of a new network is harder



NETWORK ARCHITECTURES

- Tight coupling
  - WLAN is used as access layer for the mobile services
  - An interoperability node is necessary to connect the WLAN access point to the mobile network
    - Can be implemented in RNC or SGSN
  - Reduces the delays in handover
  - The maximum throughput is given by the mobile network
  - The interoperability node has to be properly designed



HANDOVER

- Handoverul can be classified as:
  - Horizontal: in the same radio access technology
    - E.g. between different 4G cells
  - Vertical: between different radio access technologies
    - E.g. between WiFi-4G or 4G-WiFi
- Vertical handover can be classified based on multiple criteria
  - Based on RAT coverage:
    - Upward: switching from a reduced coverage network to a higher coverage network
    - Downward: switching from a high coverage network to a lower coverage network

HANDOVER

- Based on connection existence during handover:
  - Hard: the connection to the new network is made after the interruption of the existing connection, ”break before make”
  - Soft: the existing connection is maintained until the new connection is established, ”make before break”
- Based on the received signal level:
  - Imperative: when the received signal level falls below a threshold, no other parameters are considered
  - Alternative: initiated to offer higher performance for the users, takes into consideration the available bandwidth, throughput, network cost, QoS of applications, user preference
- Based on controlling device
  - Terminal controlled handover
  - Network controlled handover
  - Terminal controlled and network assisted handover

NETWORK SELECTION

- The best available radio access network must be selected
  - Network selection depends on multiple factors:
    - QoS
    - Mobility
    - Cost, etc.
  - MADM (Multiple Attribute Decision Making) methods are used based on decision tables formed of:
    - Alternatives (available networks)
    - Attributes (selection criteria)
    - Criteria weight
    - Selection performance

NETWORK SELECTION

- In case of mobile networks, the selection is based on received signal strength (RSS)
- In heterogeneous networks this method is not appropriate
  - It is possible that a network with low RSS and low load to offer better performance than a network with high RSS and high load
- Possible methods for HWN network selection
  - Fuzzy logic
  - Game theory
  - Utility function-based selection
  - Genetic algorithm-, neural network-based optimization

NETWORK SELECTION

- The network selection can be:
  - Network-centric
    - The operator controls the procedure and takes decisions
    - The congestion, due to multiple users connecting simultaneously to the same RAT, can be controlled
    - Cannot be implemented in case of multiple operators
  - User-centric
    - The decisions are taken by the users
    - Can generate congestion due to the egoistic behavior of users
      - The users try to connect to the best RAT simultaneously

NETWORK SELECTION

- The parameters used for network selection can be classified as:
  - Network parameters
    - Network load
    - Coverage area
    - Available bandwidth
    - Cost
  - Application parameters
    - Delay
    - Jitter
    - Required throughput
    - PLR – Packet Loss Rate

NETWORK SELECTION

- User-dependent parameters
  - Acceptable costs
  - Desired quality
- Mobile terminal parameters
  - Mobility support
  - Available interfaces
  - Battery status

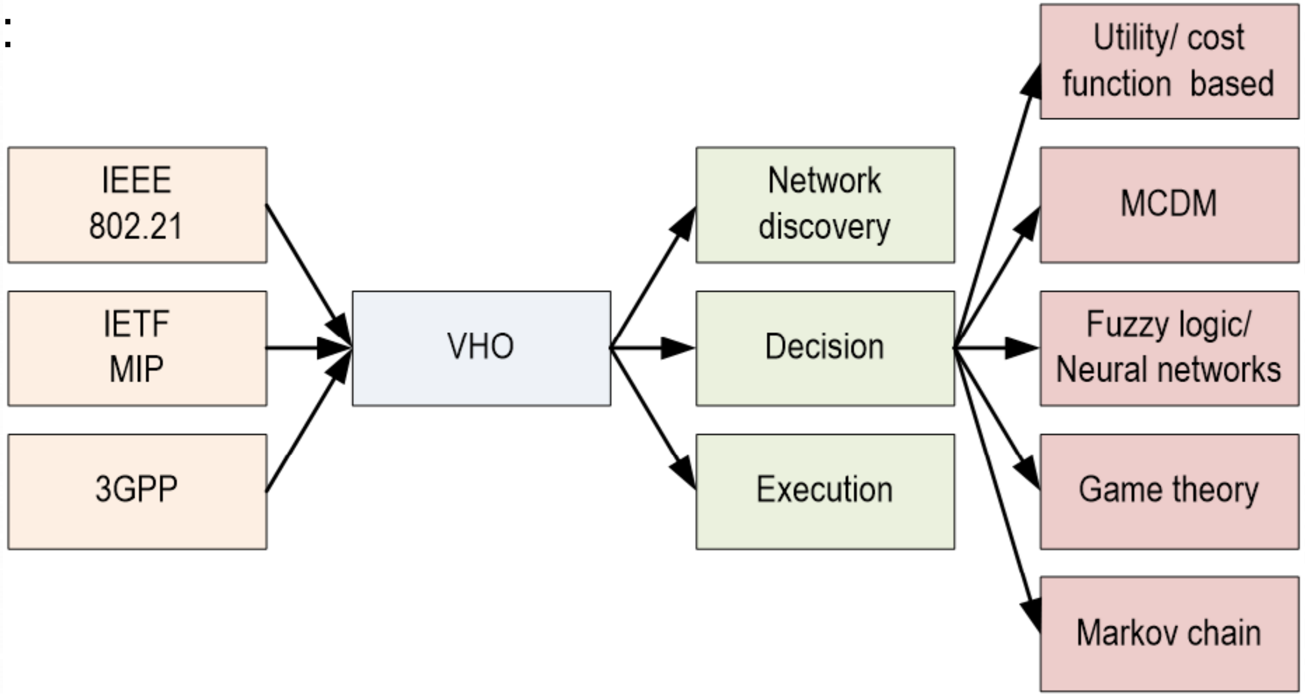
- The parameters can be static or dynamic
- The parameters have to be minimized or maximized for the selection process

NETWORK SELECTION

Group	Parameters	Type	
Network	Load	Dynamic	Minimum
	Coverage	Static	Fixed
	Connection time	Dynamic	Minimum
	Available bandwidth		Maximum
Application	Throughput	Dynamic	Maximum
	Delay		
	Jitter		
	PLR		
	Energy consumption		
User	Budget	Static	Fixed
	Cost		
Mobile terminal	Battery	Dynamic	Fixed
	Mobility		

NETWORK SELECTION

- Network selection takes place in 3 steps:
  - Monitoring
    - Available networks are identified
    - Information about network parameters is acquired
  - Decision
    - The best network, based on information and user preference, is selected
    - The classification of most suitable networks is made
  - Execution
    - The connection to the selected network is realized



NETWORK SELECTION

- MADM
  - A decision table is built
    - The alternatives are represented by RAT (lines)
    - The attributes are the parameters used for the decision (columns)
    - The weight represent the importance of each parameter (elements)
  - MADM methods: SAW (Simple Additive Weight), TOPSIS (Technique to Order Preference by Similarity to Ideal Solution), WPM (Weighted Product Model)
  - MADM can be applied only if the data is expressed in the same measurement unit
    - The normalization of parameters is necessary
    - Normalization methods used: max-min, sum, radical

NETWORK SELECTION

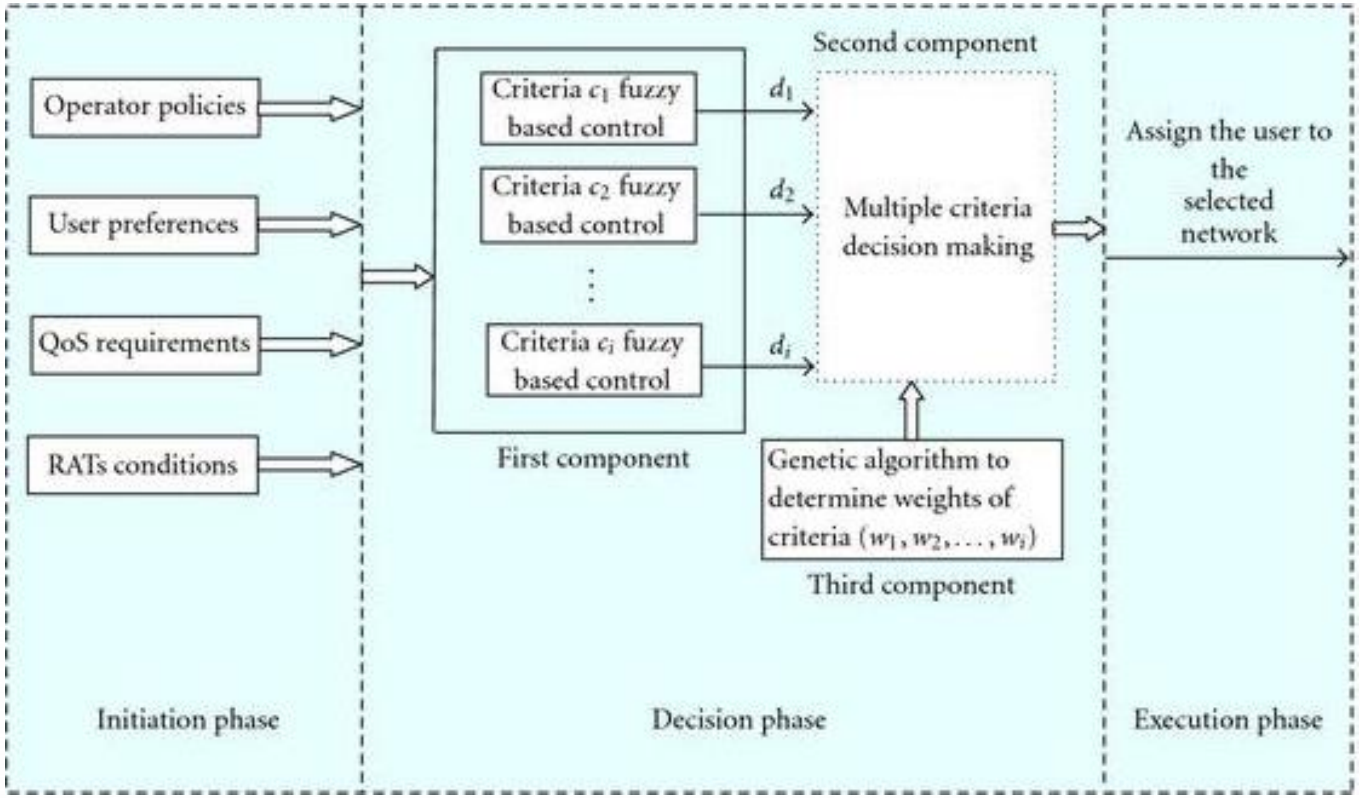
- The weights are related to the user profile and can be objective or subjective
  - The subjective weights are defined based on empirical data
  - The subjective weights can be established based on methods like:
    - Entropy: $w_j = 1 - \frac{1}{N}\sum_{i=1}^{N}\left[x_{ij} ln\left(x_{ij}\right)\right]$
    - Variance: $w_j = \frac{1}{N}\sum_{i=1}^{N} x_{ij}$
    - Eigenvector: $w(B - \lambda I) = 0$
- SAW: the data is normalized and the candidate with the lowest/highest value is selected: $R_{SAW} = \sum_{i=1}^{N}\left(w_j r_{ij}\right)$, r_{ij} is the normalized value of parameter j of network i
- WPM: offers better performance than SAW: $R_{WPM} = \prod_{i=1}^{n}\left(r_{ij}\right)^{w_j}$

NETWORK SELECTION

- Game theory
  - One game is represented by 3 sets
    - The set of players who want to maximize their gain
    - The set of actions or strategies which depend on available information
    - The gain of players based on the strategy
      - If the gain cannot be increased by other strategies for any of the players, the Nash equilibrium is reached
  - For network selection multiple possibilities are available:
    - Game between users: each of them wants maximum throughput
    - Game between networks: each of them wants to maximize the number of users
    - Game between users and networks

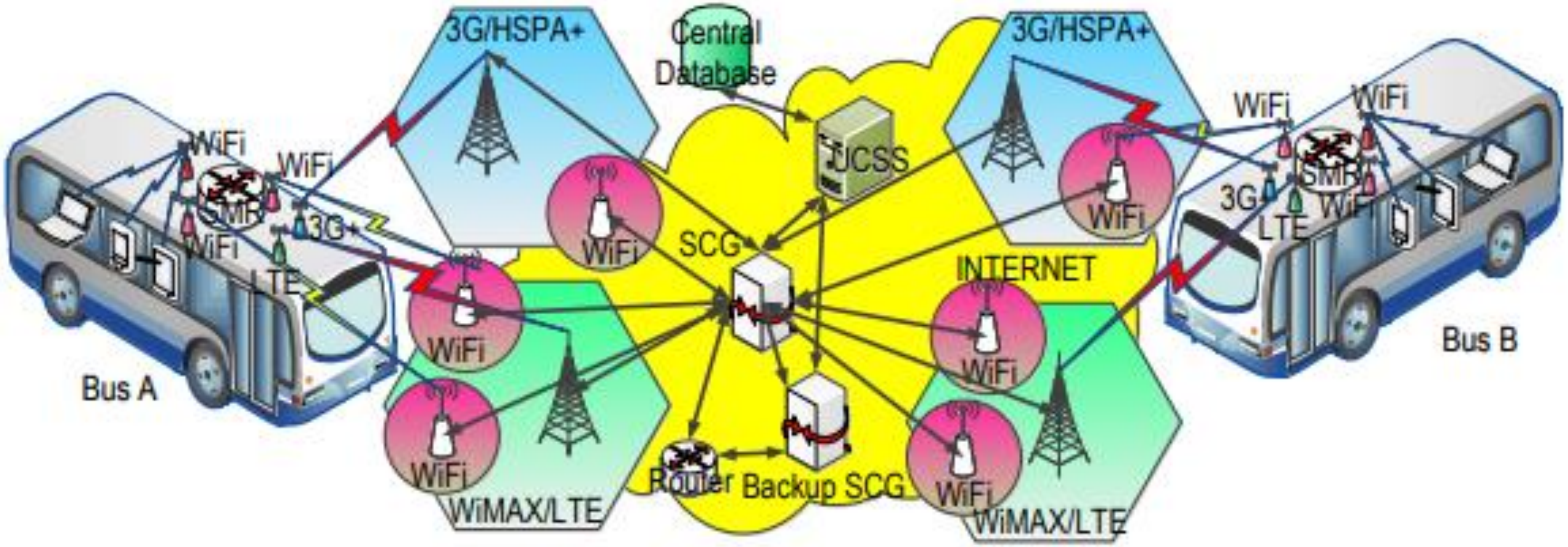
NETWORK SELECTION

- Fuzzy logic
  - Fuzzy algorithms can be used alone or in combination with MADM



POSSIBLE APPLICATION OF HWN

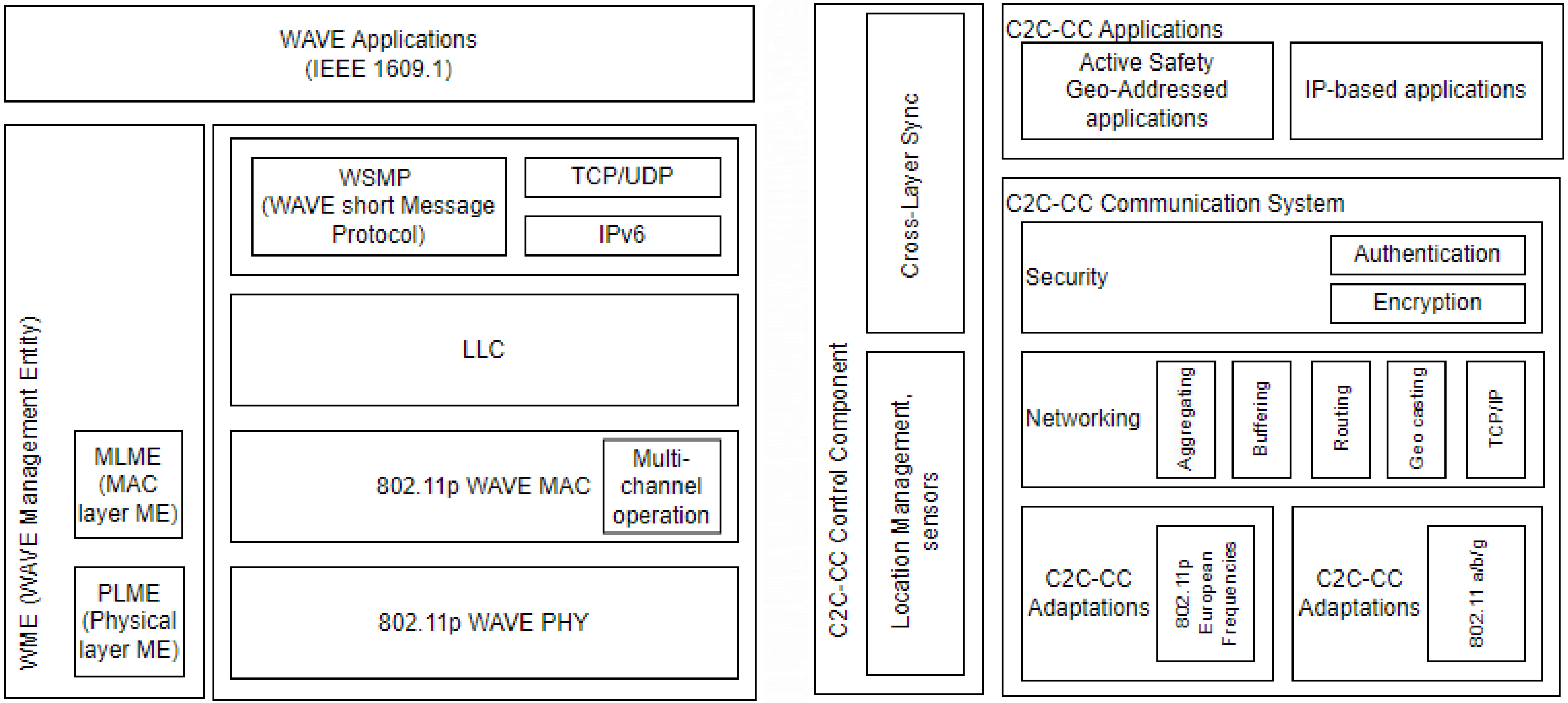
- Ubiquitous connectivity solution for the passengers of public transportation vehicles
  - Developed in the FP7-UCONNECT research project



STANDARDIZATION

- IEEE developed the WAVE (Wireless Access in the Vehicular Environment) architecture
  - WAVE is based on IEEE 802.11p (DSRC, Dedicated Short Range Communications)
    - Allows in-car OBU (On-Board Unit) to communicate with other cars or with RSUs (Road-Side Unit)
    - A management plan and the capabilities to manage multiple channels is added to the legacy 802.11 standards
    - The standard was adapted to Europe in C2C CC (Car to Car Communication Consortium)
    - IPv6 has been chosen to provide Internet connectivity in the WAVE architecture
    - It does not allow heterogeneous networking and has no routing features
- The C2C-CC architecture is derived from the WAVE architecture
  - It is mainly devoted to safety ITS related applications
  - It uses WLAN to provide multi-hop V2V communications and V2I communications
  - It cannot manage heterogeneous wireless access, but can use the public IEEE 802.11 hotspots
  - The C2C-CC system routes the traffic to the best suited interface encapsulating IPv6 packets in C2C-CC frames

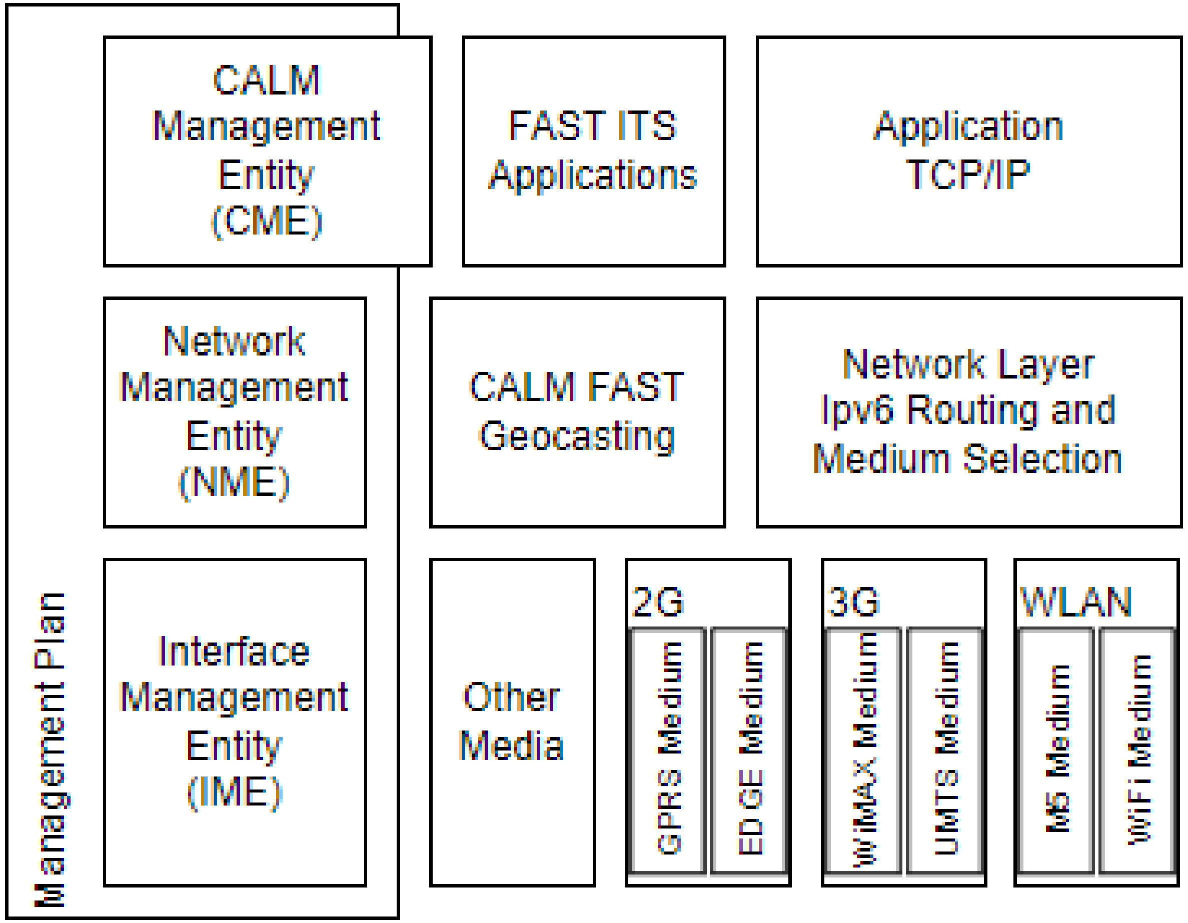
STANDARDIZATION



STANDARDIZATION

- The CALM architecture (Communications Access for Land Mobiles) is designed by the ISO technical committee
  - It aims providing users with transparent continuous communications across multiple heterogeneous wireless access networks
  - The architecture is open and evolutionary to tackle with the differences between communication technologies and cars lifetimes
  - It has been explicitly designed to support heterogeneous networking of multiple access technologies (802.11, 3G/4G, WiMAX, etc.) through dedicated convergence layers
  - The IP network layer consists of IPv6, Mobile IPv6 and NEMO defined by IETF
  - Applications could be CALM-aware or not, CALM-aware applications interact with the management plan and send the requirements to the management plan
  - The management plan controls the network layer to route applications flows to the interface that better meets the given requirements

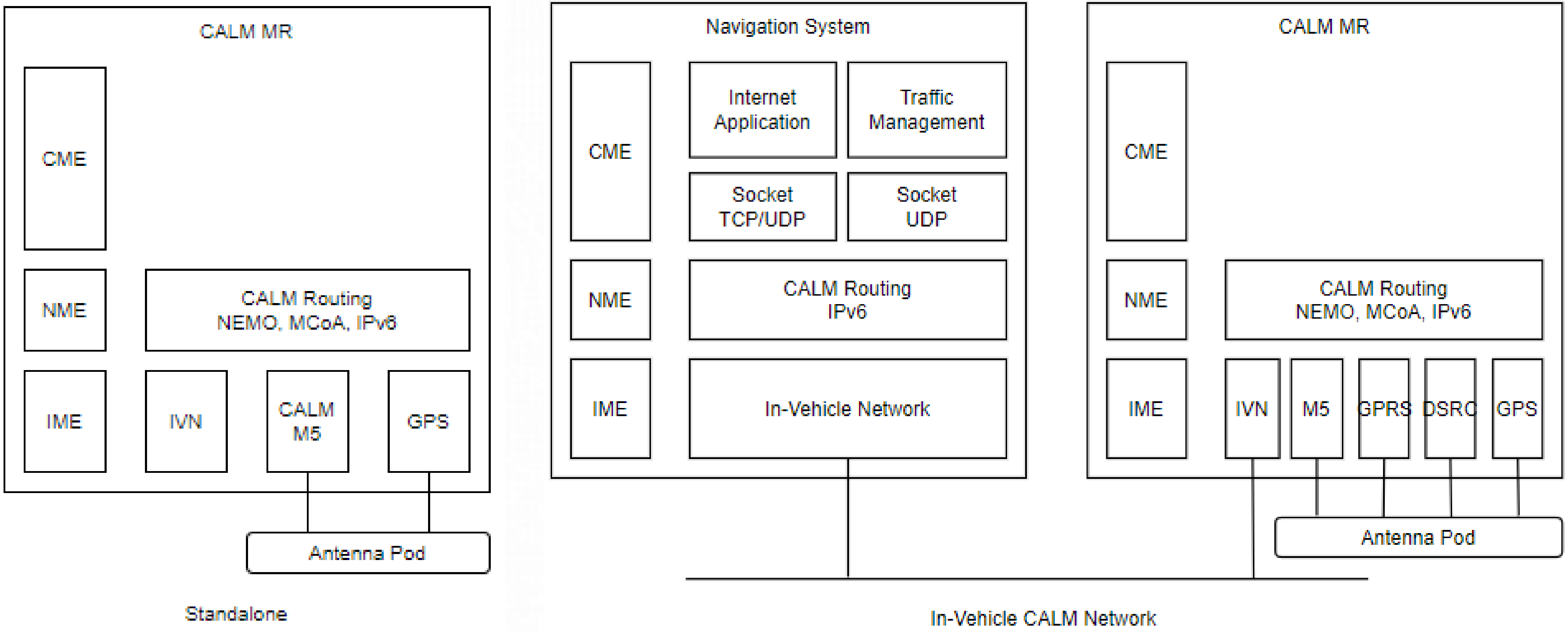
STANDARDIZATION



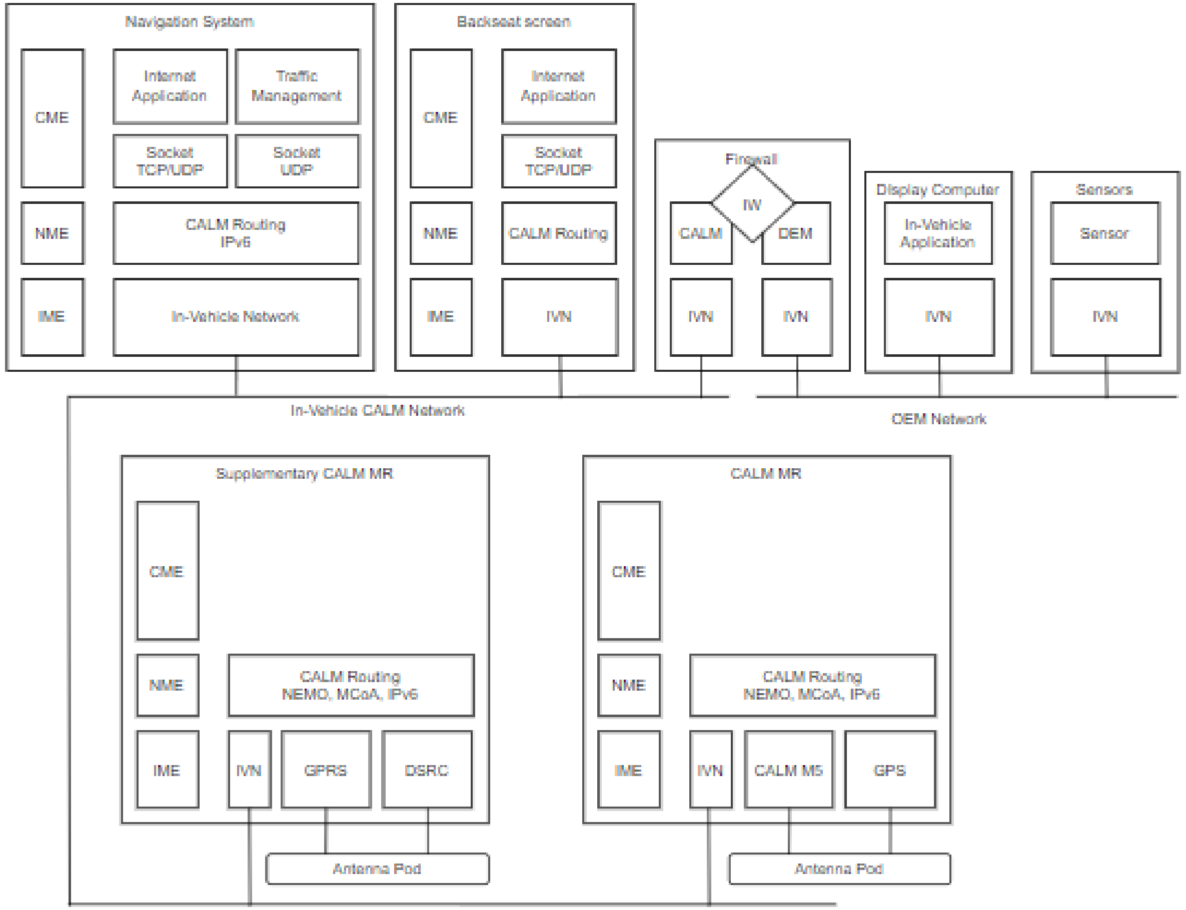
STANDARDIZATION

- The CALM Modem (MR) is responsible for interface management and connectivity continuity
  - All other on-board equipment only have to support IPv6 networking and implement a simple version of the CALM management plan
  - It is easy to integrate IPv6 devices as they are allowed to communicate as if they are on the fixed Internet
- CALM deployment scenarios:
  - Standalone deployment: a single CALM device with no IPv6 connectivity to other on-board devices
  - CALM on-board and CALM enabled devices
  - Full CALM implementation: allows progressive deployment
    - A CALM mobile router is built-in the vehicle by the manufacturer and devices could be added during the vehicle's lifetime
      - A new CALM router may provide new wireless interfaces and cooperate with other CALM devices to transparently enhance the Internet experience of the user

STANDARDIZATION



STANDARDIZATION



A full CALM implementation

MOBILE ROUTER FEATURES

- Main features that have to be present in a mobile router in order to manage multiple interfaces:
  - Multiple Path Management
    - The ability to handle several paths simultaneously
    - Mobile Routers should be connected through multiple networks and technologies at the same time to be efficient
  - Per Flow Path Selection
    - Settling multiple paths can be useful for backing up traffic
      - When an interface is disconnected, another interface is ready to take over the flow
    - Multiple paths can also be used to increase reliability by duplicating traffic over several paths at the same time
    - Per flow dispatching: this allows the user to select the most appropriate path or access network for each flow
      - Routing decisions should change each time a new interface becomes available or disappears
      - Network layer should be provided with enough information to react timely to a change in the networking conditions

MOBILE ROUTER FEATURES

- Advanced Interface Management
  - Simultaneous use of several network interfaces has a lot o advantages
    - However, these interfaces could be power consuming and power can be a limited resource in mobile environments
    - Some connections can be billed according to the duration rather than the amount of data sent
      - It is not a good solution to keep the interfaces running all the time
    - An advanced management system is necessary to bring interfaces up when critical flows have to be sent and shut down when the transmission is terminated
- Dynamic Network Selection and Switching
  - It is common for network interfaces to have several wireless networks available at the same time
    - The number of wireless networks is expected to increase and the performance of a mobility management system can be improved by a comprehensive dynamic selection of the best network
    - MRs should be able to monitor the available wireless networks and evaluate (more or less) the performance of each one

MOBILE ROUTER FEATURES

- Multiple MR
  - Most of the solutions proposed do not deal with multiple MRs
  - Nevertheless, MR redundancy can be interesting, particularly in trains where MRs can be distant and take profit from a larger set of wireless networks
  - Multiple MRs also could be useful when hand-held devices are used as MRs
- High-Level Decision Modules
  - Rather than applying a predefined set of routing rules, these rules can be generated automatically using high-level, human friendly, objective definitions
  - Other representations of high-level usage policy can be used, like fuzzy logic or policy-based language
    - It is important to allow the user to specify generic goals instead of specific situations
      - This would help in making the system more autonomous
      - It is more efficient if the decisions are made by accurate decision algorithms

MOBILE ROUTER FEATURES

- Support of Mobility-Aware Applications
  - Applications requirements, in terms of bandwidth, delay, jitter, etc., are getting increasingly diverse
  - Adaptive applications may adapt their own behavior to resources available on the different access networks
    - Adaptive applications and network architectures have to interact tightly this is more complex in a context where applications do not run on the device that manages the interfaces
    - It is necessary to exchange information between the MR and the embarked devices two operation modes could be envisioned:
      - The MR announces available resources and each application decides on its own to adapt its behavior
      - The MR performs a centralized resource management taking into account requirements declared by the applications
        - Offering a unified way to obtain mobility related information is important for interoperability concerns this will enable applications to participate in the process
        - Proposed protocols have to be as maintainable and flexible as possible to foresee future technology evolutions and needs

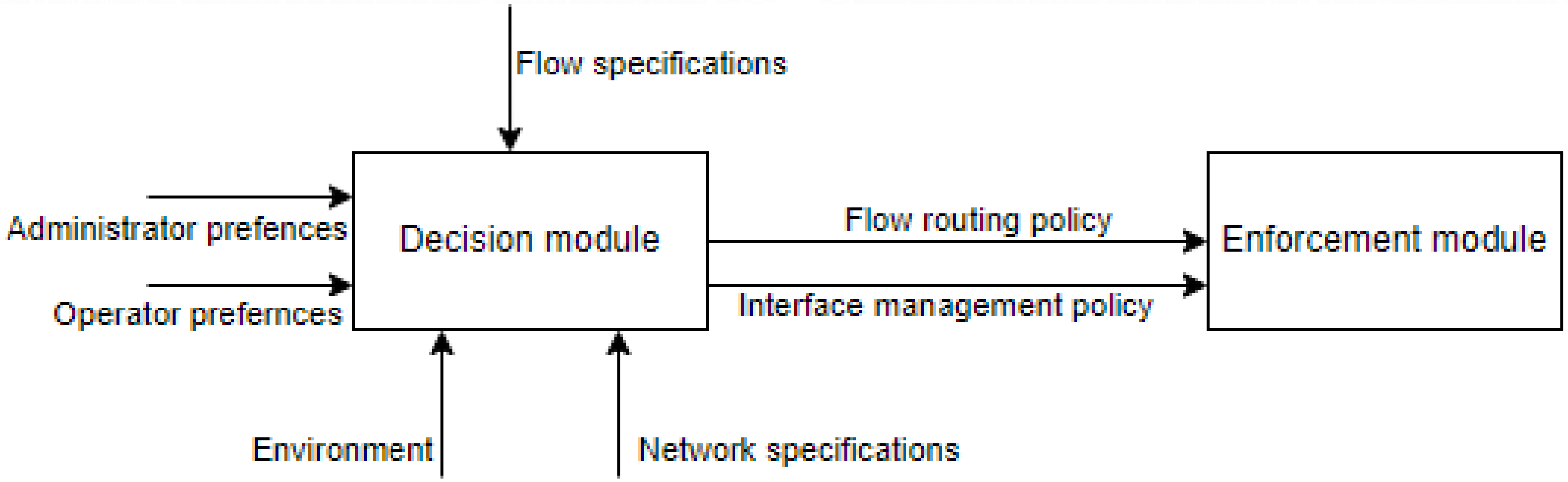
FULL-FEATURE ARCHITECTURE

- The communication architecture for ITS includes modules divided into three categories:
  - Monitoring Modules, Decision Modules, Enforcement Modules
- The overall architecture is built on a network device which uses mobility management schemes
- Architecture Overview
  - Monitoring Modules monitor the system environment to collect data necessary for the decision process
    - Data collected may include vehicle speed, geolocation , battery status, available wireless networks
  - Decision Modules have three types of input:
    - Data collected by the Monitoring Modules
    - Preferences of operators, system administrators, final users
    - Flow requirements

FULL-FEATURE ARCHITECTURE

- The decision process consists in three policies:
  - Interface Management Policy; Routing Policy; Application Policy
  - Once produced these policies are delivered to be enforced
- Enforcement Modules are in direct interaction with the network layer of the operating system's kernel
  - Dedicated enforcement modules are hard to maintain since operating system kernel are constantly evolving
  - The mobility management framework should use extensively the high-level tools offered by the system
    - In this case the role of the Enforcement Modules consists mainly in translating and adapting the policies produced by the Decision Modules to the current operating system tools
      - Such a framework is much easier to maintain and could be easily ported on multiple platforms

FULL-FEATURE ARCHITECTURE



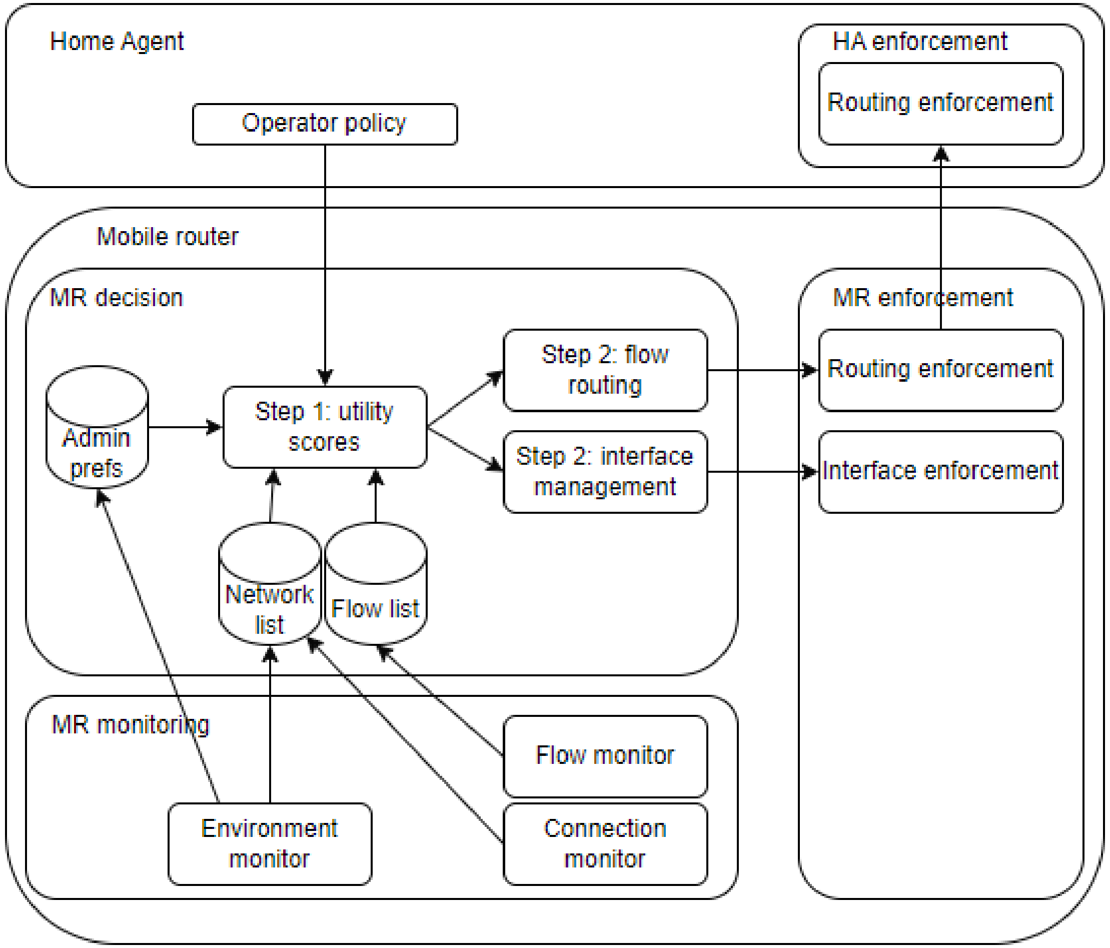
FULL-FEATURE ARCHITECTURE

- Monitoring
  - A user may want to differentiate the behavior depending on certain parameters
  - It is preferable to have a fully autonomous system that is configured using high-level parameters allowing the system to react in function of the current context
  - The sensing features allow the MR to be aware of the environment
    - Providing up-to-date information to decision modules allows obtaining a reactive system that takes accurate decisions
    - An essential information that must be monitored to be “Always Best Connected” is the available wireless networks the role of the Connection Monitor
    - The Connection Monitor listens passively to wireless access networks and informs Decision Modules about their availability
      - It also monitors the performance of wireless networks currently in use, allowing the system to react upon a change in the networking context

FULL-FEATURE ARCHITECTURE

- A Flow Monitor is necessary to provide information about the currently conveyed flows, it allows the system to evaluate the needed resource level and to adapt itself to flow requirements
- The Environment Monitor
  - Among the monitored parameters the vehicle speed is very interesting
    - It allows, for example, to privilege WiFi networks when the vehicle is stationary and 3G/4G networks when it is moving
  - Time and date parameters give the possibility to choose cheaper networks
  - It allows also differentiating the system behavior depending on whether it is work time or free time
  - Another parameter to monitor is battery level
    - Allows the system to decide if it should limit power consumption (e.g., when vehicle engine is stopped) or if it can act regardless of power consumption
  - This monitoring module should be highly configurable and should allow user to monitor any value that can be asked for through a simple script (for example)

FULL-FEATURE ARCHITECTURE



FULL-FEATURE ARCHITECTURE

- Configuration
  - Administrator Preferences
    - The system configuration has to be decontextualized instead of giving the value of a parameter, the administrator should rather give different values in different contexts
      - Conditional statements in human-like language (which easily can be modified by the user) should be provided
  - A configuration file should have three main sections:
    - A first section should specify the objectives: which are the parameters that the administrator needs to maximize or to minimize
    - The second section gathers the different operating modes of the system the operating modes indicate the weight of each “performance” parameter the higher the weight is, the more important the parameter will be
    - The last section is the algorithm that allows selecting the adequate operating mode in function of the context variables

FULL-FEATURE ARCHITECTURE

```
Section Objectives:
Minimize Cost;
Minimize PowerConsumption;
Maximize Bandwidth;
Maximize ConnectionStability;
Maximize Security;
Minimize Jitter;
Maximize OperatorSatisfaction;

Section Modes:
CostEconomy
{
        Cost = 100
        Bandwidth = 20
        PowerConsumption = 0
        ConnectionStability = 10
        OperatorSatisfaction = 20
}
MaxStability
{
        Cost = 10
        Bandwidth = 70
        PowerConsumption = 0
        ConnectionStability = 100
        OperatorSatisfaction = 20
}
```

```
MaxBandwidth
{
        Cost = 10
        Bandwidth = 100
        PowerConsumption = 0
        ConnectionStability = 70
        OperatorSatisfaction = 20
}
PowerEconomy
{
        Cost = 50
        Bandwidth = 20
        PowerConsumption = 100
        ConnectionStability = 20
        OperatorSatisfaction = 20
}

Scetion Pseudo Algorithm
VehicleLocation in {'Romania'}
        BatteryLevel in [20...100]
                DayOfWeek in {'Saturday','Sunday'}
                        RETURN CostEconomy
                DayOfWeek in other
                        HourOfDay in [9...17]
                                VehicleSpeed in [0...30]
                                        RETURN MaxBandwidth
                                VehicleSpeed in other
                                        RETURN MaxStability
                        HourOfDay in other
                                RETURN CostEconomy
        BatteryLevel in [0...20]
                RETURN PowerEconomy
VehicleLocation in other
        RETURN CostEconomy
```

FULL-FEATURE ARCHITECTURE

- Operator Preferences
  - The most viable solution to handle the operator influence on the decision process is to generate a set of generic rules (i.e., for all users) that associate for each flow type (i.e., port number) a list of mandatory networks, a list of preferred networks and a list of forbidden networks
  - The administrator should have a way to limit the impact of the Operator Preferences on the decision
    - Nothing is specified in the CALM architecture to allow operator policies to be taken into account in the decision process nor to exchange such policies
- Network List
  - In order to chose among several networks, the system has to identify them and evaluate their performance and their cost
  - A Network List should contain an entry for each known network specifying its cost, its characteristics and a way to identify it and to connect to it

FULL-FEATURE ARCHITECTURE

- The list has to specify all the networks that the MR can connect to
- Generating and maintaining the list involves several steps:
  - The Network List could be filled by the administrator or downloaded from a server
  - Addition of the performance parameters which should be dynamically updated
  - Automatic filling of the list if unknown networks are detected and no other known network is available
  - Contextual filtering of the list to reduce the number of entries considered in the decision process
    - For example, taking into account GPS positions and other information in order to evaluate the probability of availability of known networks
  - The Network List can also be decontextualized, i.e., the user can specify characteristics (performance, cost, etc.) that depend on the context the most obvious example are the billing schemes

FULL-FEATURE ARCHITECTURE

- Flow List
  - A Flow List should contain the types of flows to be conveyed
  - For each flow it is necessary to specify how to recognize the belonging packets
    - A Flow Monitor adds information about whether the flow is alive or not and evaluates the bandwidth currently used by each flow
    - The administrator may also add a priority value to certain flow types
      - For ex. a videoconference flow could have higher priority than a video streaming flow
    - In addition, the Flow List specifies the minimum requirements for each flow
      - A network that does not meet the requirements is not considered as a candidate in the decision
      - When there are more candidate networks, the system must select the best fit for flow needs
    - To influence the decision, a flow can indicate in the Flow List the relative importance it gives to network parameters

FULL-FEATURE ARCHITECTURE

- Decision
  - The decision process has to take into account high-level considerations such as operator preferences, all available networks and all flows to be routed
    - This could result in a heavy process that could not be triggered each time something happens
  - In a mobility context, network events (handover, disconnections, etc.) are frequent and require fast reaction that cannot be afforded while taking into account an important number of parameters to overcome this, the decision process should be split in two steps:
    - First step: evaluation the matching degree of flows with the networks stored in the Network List while respecting the restrictions and preferences of the operator, administrator and the flows
      - To achieve this a utility score could be computed for each network flow tuple; the greater the score is, the more compatible the tuple is
    - Second step: has two tasks:
      - Route the flows through the different tunnels available
      - Bringing up and down interfaces as needed and looking for “better” networks

FULL-FEATURE ARCHITECTURE

- Decision – First Step: Utility Scores
  - The information provided by monitoring modules is combined with the Flow List, the Network List, the operator preferences and the administrator preferences
  - Weights provided by the different inputs allow to obtain a utility score for each network flow tuple
    - The score is computed not only regarding the networks currently used, but also the networks that are potentially reachable
  - The output of this step is a list of flows and for each flow, a list of compatible networks and their respective utility scores

FULL-FEATURE ARCHITECTURE

- Decision – Second Step: Flow Routing
  - Consist in distributing flows over available interfaces while sharing resources
    - Priority flows are served first and the other ones can be dropped if needed
    - The overall objective is to maximize overall flow satisfaction regarding flow priorities
    - The decision process tries to find alternative access networks that can fit better aggregated flow requirements
    - Some interfaces can be brought down to save energy and cost
  - The output is a set of FlowIDs with a list of zero or more NetworkIDs scores attached to each FlowID
    - The flow profiles that do not have any NetworkID attached are simply discarded
    - The flow profiles that have a single NetworkID attached are conveyed through the corresponding tunnel
    - The flow profiles that have several NetworkIDs attached can be handled in several manners
      - Choose the network with the highest score does not guarantee a satisfactory load sharing
        - For an overall satisfaction increase, the 2nd and 3rd tunnel choices can be considered
        - For such a decision an approximation of the bandwidth needed by each flow, as well as an approximation of the bandwidth currently available for each tunnel is needed

FULL-FEATURE ARCHITECTURE

- Decision – Second Step: Interface Management
  - The Interface Management module is in charge of continuously looking for a better and cheaper network
  - To evaluate the need for a network the network-flow tuples scores are used and the combination of flow and reachable network scores are computed
    - The combination is chosen and the module generates the policy that reflects this decision
    - Hysteresis is necessary to avoid redirecting flows back and forth on the interfaces
  - The module is responsible for cost and power mastering
    - It shuts down interfaces when they are not really needed this in case when there are no critical flows that require the interface and the non-critical flows can be dispatched on the other interfaces
  - The result obtained is a list of interface-network tuple
    - The indicated interfaces should be active if needed and connected to the corresponding networks; the other interfaces have to be deactivated
    - Once this policy is enforced the Flow Routing Decision Module will adapt itself and redirect the flows conveniently

FULL-FEATURE ARCHITECTURE

- Enforcement
  - This module is simple comparatively to the previous ones
  - It translates the decision modules policies into system commands
  - The Interface Enforcement module operation consists in calling interface configuration system commands
    - The module configures the interface and reports whether the operation was successful or not
  - The Routing Enforcement module has to act on both the MR and HA (Home Agent)
  - The policy exchange, which could be completely independent, can be achieved using HTTP/SOAP or any other protocol
    - This solution allows flexibility and allows to the user the ability to create and exchange complex policies

FULL-FEATURE ARCHITECTURE

- Mobility-Aware Application Management
  - The architecture described aims to optimize the satisfaction of the operator, administrator and the applications through high-level decision modules
    - Application satisfaction is basic since it is based upon static flow descriptions
      - Applications requirements change through time and depend closely on available resources and user preferences
    - In the standard IP model, applications do not have to be aware of network status
      - This solution is satisfying in the wired networks since link conditions are relatively stable, but, in a mobility context, conditions can vary widely and can no longer be efficient
  - Application requirements, in terms of bandwidth, delay, jitter, etc, are very different
    - Some critical applications need low bandwidth but constant connectivity (medical monitoring)
    - Some other applications, such as VoIP, need a certain amount of bandwidth and are very sensitive to delay and variation in packet arrival time may prefer not operate if requirement are not fulfilled
    - FTP-like applications just need as much bandwidth as available

FULL-FEATURE ARCHITECTURE

- There are more complex cases where application needs depend on the resources available
  - A mail client can wait to be over a high-speed network to download the mail attachments
  - A videoconference application can also reduce its needs by transmitting only voice and blocking video
- More generally, applications and network architecture have to interact to be more reactive to network changes and to distribute the available bandwidth in a clever manner
  - This level of interaction, i.e., Mobility-Aware Applications are necessary
    - These are high-level applications that have network awareness features allowing them to participate in the network's resources management and benefit from information given by the MR
    - Making applications aware of mobility context and offering to them the possibility to interact with the decision modules has as consequence an effective improvement of the global bandwidth as well as a better dispatching of the flows on the different network interfaces
  - When applications, network interfaces and decision modules are on the same physical device it is relatively easy for applications to monitor network status and react in consequence

FULL-FEATURE ARCHITECTURE