Mobile Internet

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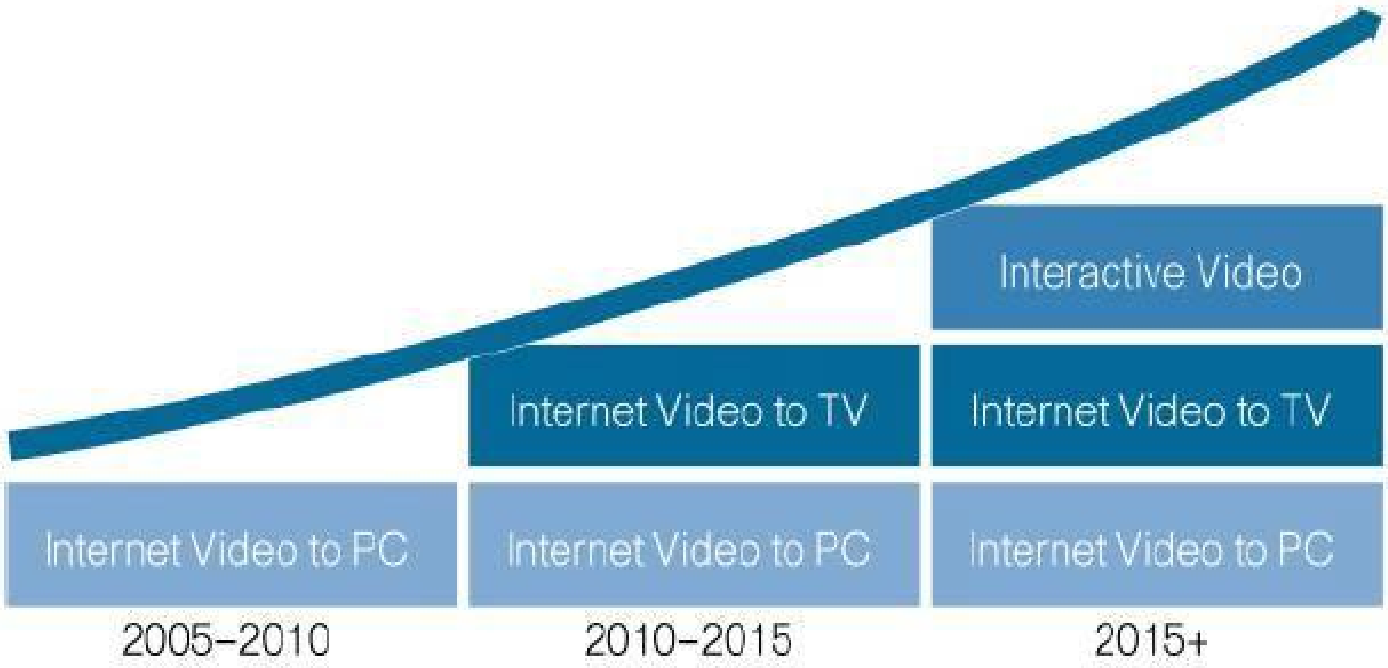
Outline

- Trends in data communications
- Challenges
- Research directions
- Research examples

Trends in data communications

- Exponential increase in volume of data traffic
  - Traffic in wireless access expected to get k $\times$100 – 1000 fold within next ten years (mobile traffic more than doubled each year since 2009)
  - Smartphones and tablets exacerbate pace (e.g. smartphones generate 35 times more traffic than conventional cellphones)
  - More bandwidth (bits/s) per user and per service (e.g. IP television moves from SDTV to HDTV and UHDTV).
- Exponential increase in energy consumption
  - 2-3 % of electricity spend for data communications (in western countries)
  - Fast growing traffic volumes entail fast increase in power consumption
    - obvious need to cut energy consumption per bit
  - Electricity consumed in networking equipment estimated to grow 13 fold by 2025 if no energy-saving measures taken
  - 70 % of power consumed (in telecom) is spend in access

Three waves of Internet video



Internet Video Will Generate Three Waves of Consumer Internet Traffic Growth

Trends in data communications (cont.)

- Communications gets increasingly wireless
  - Wireless terminals become more common
    - ✓ remote metering and control, M2M communication, sensor networks
  - Devices at home get more wireless (WiFi, ZigBee, Bluetooth)
  - Home appliances starting to communicate wirelessly
    - ✓ short range P2P, TransferJet, Wireless USB, Dedicated Short Range Communications/DSRC, EnOcean, Near Field Communication/NFC)
  - Almost everything goes wireless

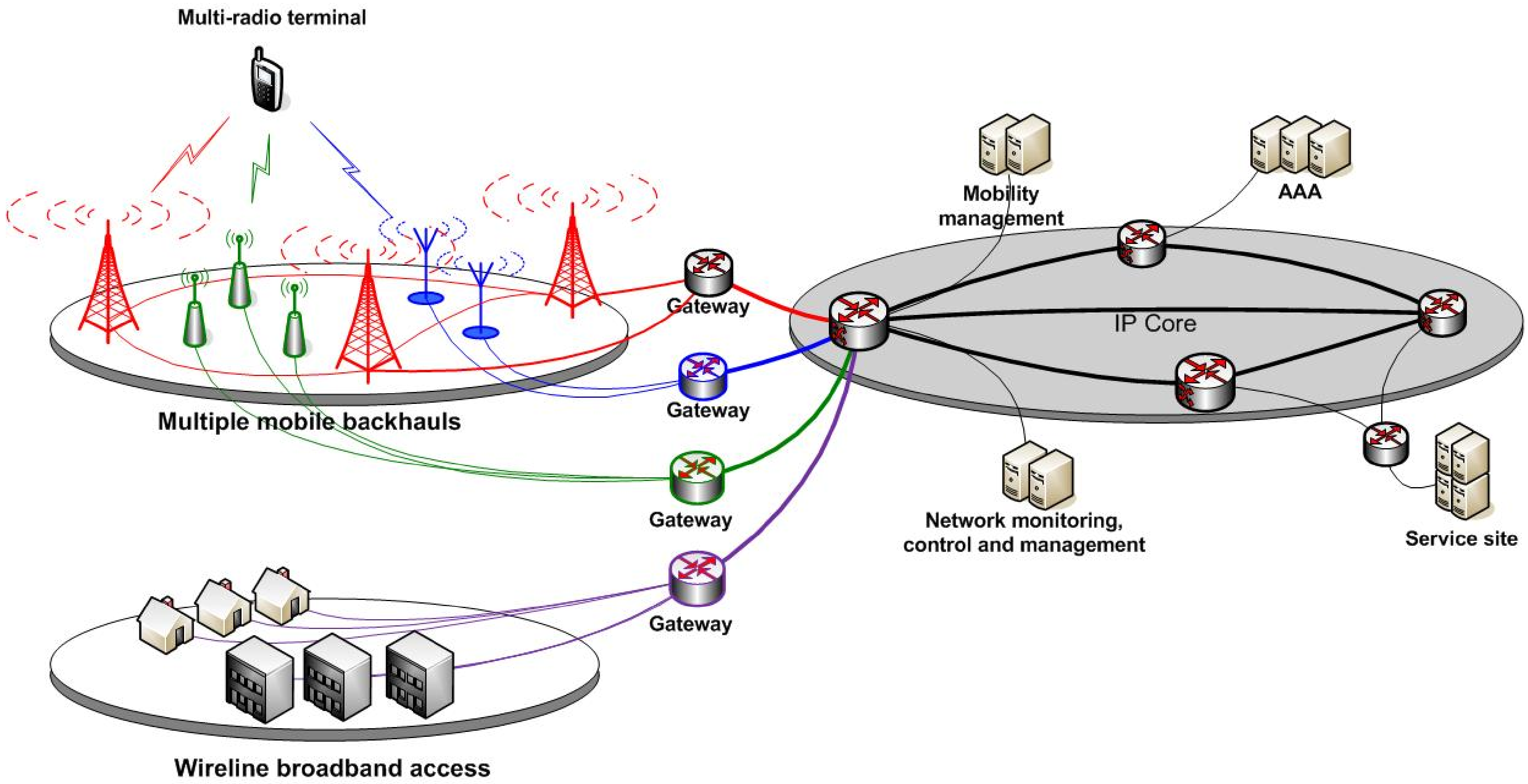
Trends in data communications (cont.)

- Mobility and interworking of different (access) networks
  - Access to personal data anytime-anywhere becoming common place
  - Operators planning to offer unlimited access to specific services (all-you-can-eat or all-you-can-app services)
  - Multiple networks accessed and used because
    - ✓ preference network not always available (accessible)
    - ✓ cheaper connections available in other networks
    - ✓ better service quality available in other networks
  - Interoperability needed
    - ✓ radio access (frequency bands, modulation, error recovery and control, handshaking/authentication/transport, etc. procedures and protocols)
    - ✓ rerouting of data in backhaul and core (e.g. Internet protocol performance)
    - ✓ management and control of connections and network devices/entities

Trends in data communications (cont.)

- Increasing complexity
  - Explosive increase in number of end-user terminals (especially networking of sensor devices and M2M)
  - Considerable increasing in number of system components, such as base stations, gateways, routers and switches
  - Multiple access technologies supported in parallel
  - Interoperability of parallel network systems
- Explosive increase in need for processing capacity
  - Frontend processing: more bits per Herz while higher frequencies deployed
  - Increasingly complex applications require more processing power
  - Explosively increasing data traffic entails more processing capacity in network nodes (routers, gateways, etc.)
  - Latencies due to data processing must be cut down

Interworking of multiple access networks

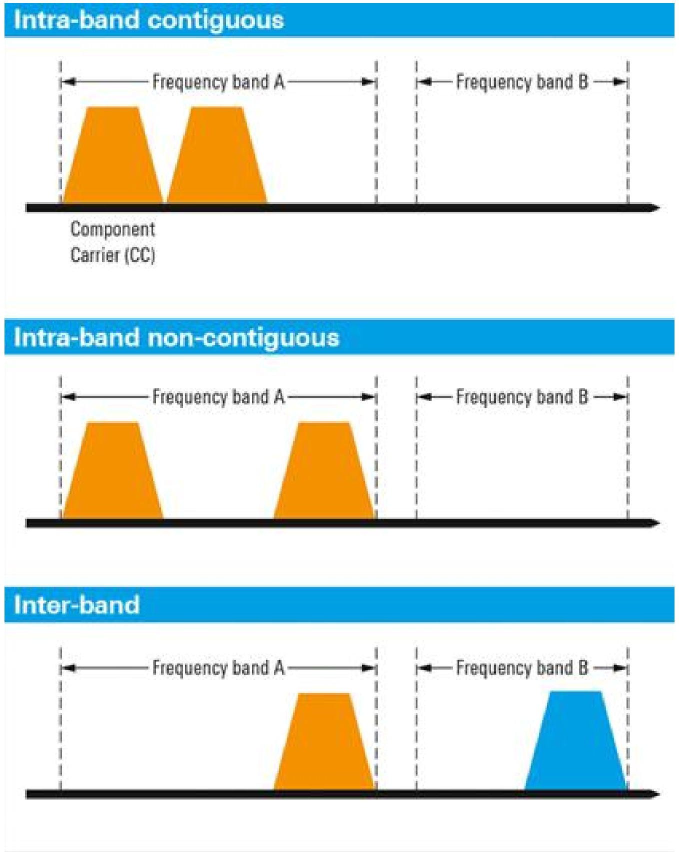


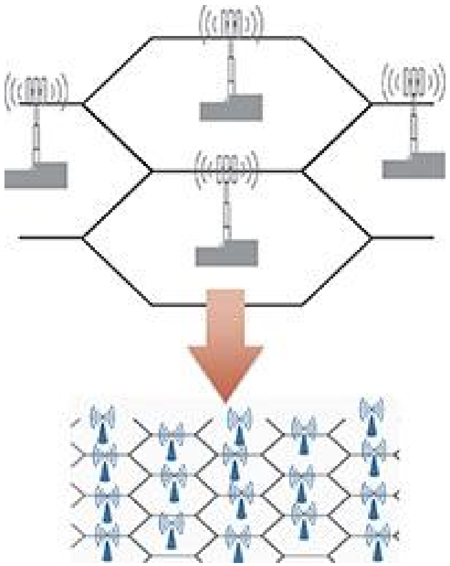
Research challenges

- Shortage of frequencies
  - Spectral exhaustion continues to exacerbate in many countries and demand will exceed supply
    - ✓ smartphones and tablets make matters worse
  - Cellular and broadcast networks utilize strictly regulated frequencies
  - Reallocation of frequencies, e.g. analog TV bands (TV white space) reallocated for mobile communications
    - ✓ less spectrum for future TV broadcasts (HD and UltraHD)
  - Use of frequencies needs to be intensified
    - ✓ spectral efficiency needs to be increased, e.g. more efficient modulation and error recovery schemes
    - ✓ more efficient compression techniques
    - ✓ cognitive radio and network concepts adapted to utilize available frequencies more efficiently

Research challenges

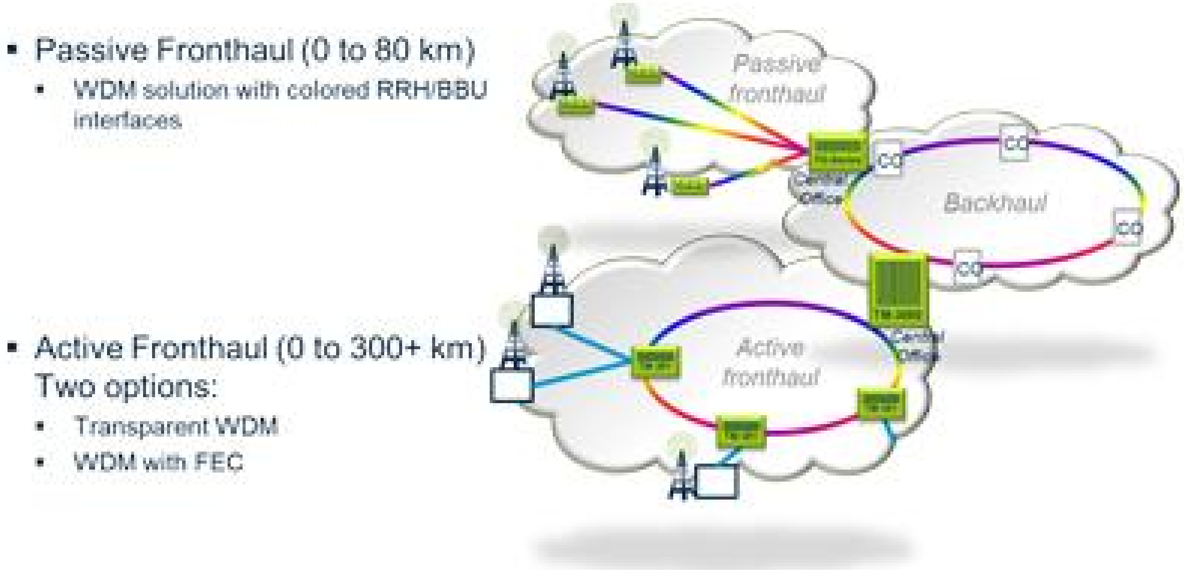
- How to meet capacity demand, reduce energy per bit and reduce latency
  - Air interface
    - ✓ Intensify spectral efficiency
    - ✓ Utilize fragmented spectrum
    - ✓ Utilize intra- and inter-carrier aggregation
    - ✓ Use beam forming techniques
    - ✓ Develop active antenna systems
    - ✓ Use massive MIMO systems
    - ✓ Use small (pico/femto) cell technologies to obtain more cells and capacity per km^2





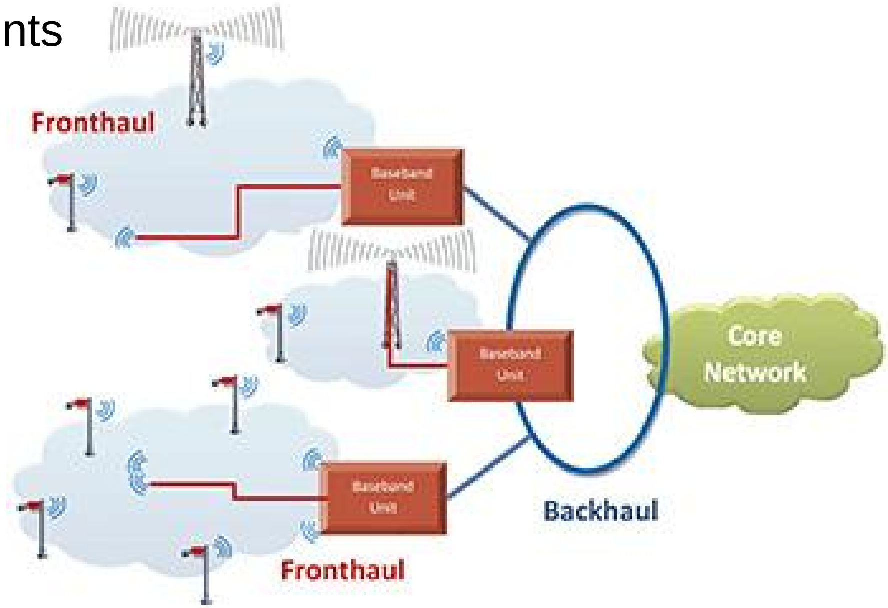
Research challenges

- How to meet capacity demand, reduce energy per bit and reduce latency (cont.)
  - Fronthaul
    - ✓ optical (WDM) transport to give capacity and fast transport
    - ✓ faster baseband processing at frontend to lower latency
    - ✓ frontend processing to cloud
    - ✓ centralized processing to lower energy consumption



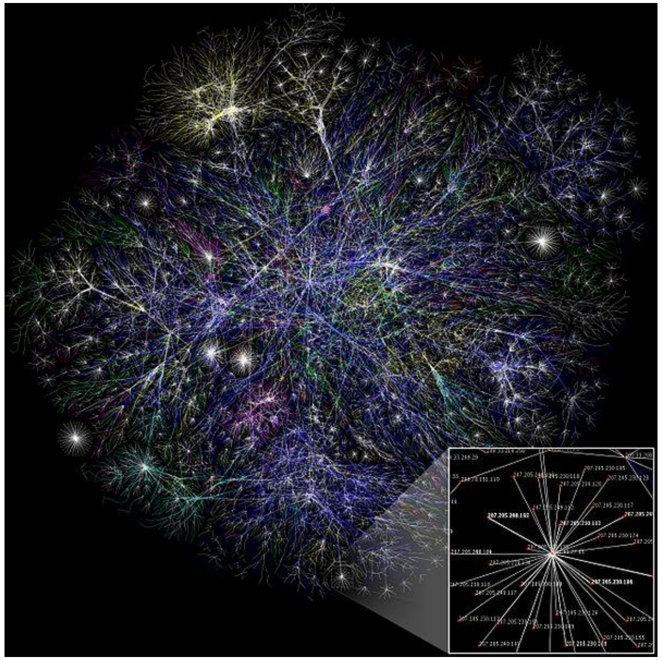
Research challenges

- How to meet capacity demand, reduce energy per bit and reduce latency (cont.)
  - Backhaul
    - ✓ fibre transport to lower latency and increase capacity
    - ✓ microwave links to cut installation time and cost
    - ✓ more processing power to network nodes/elements (e.g. gateways, routers and switches)
  - Backbone (core) network
    - ✓ all optical to increase capacity and cut latencies
    - ✓ optical switching to speed up forwarding and capacity allocation



Research challenges

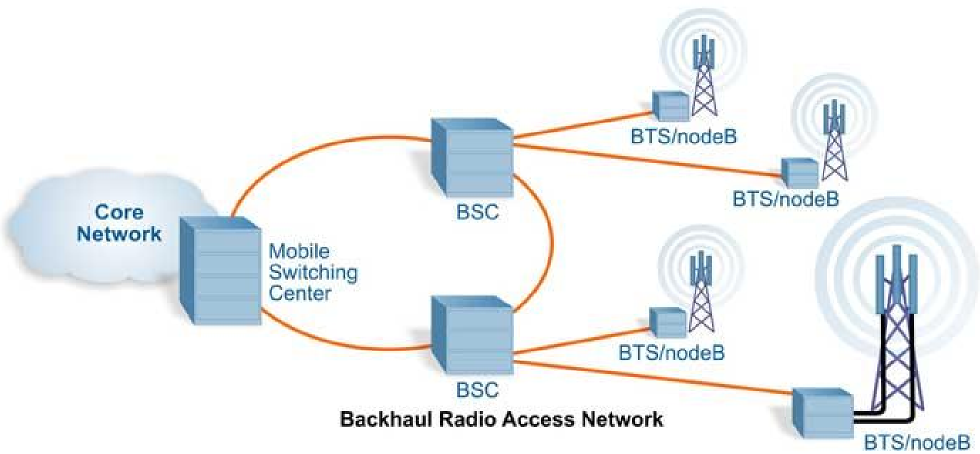
- How to manage increasing complexity when having
  - Heterogeneous mobile access (multiple cell layers)
  - Virtualized network resources with QoS/QoE support
  - Autonomic networks with learning capabilities
  - Automated real-time diagnostics and monitoring



- How to manage customer experience in networks and applications
  - Device network configurations
  - Traffic steering
  - QoS/QoE measurements
  - Coding/decoding techniques (better PLR and lower bit rate)

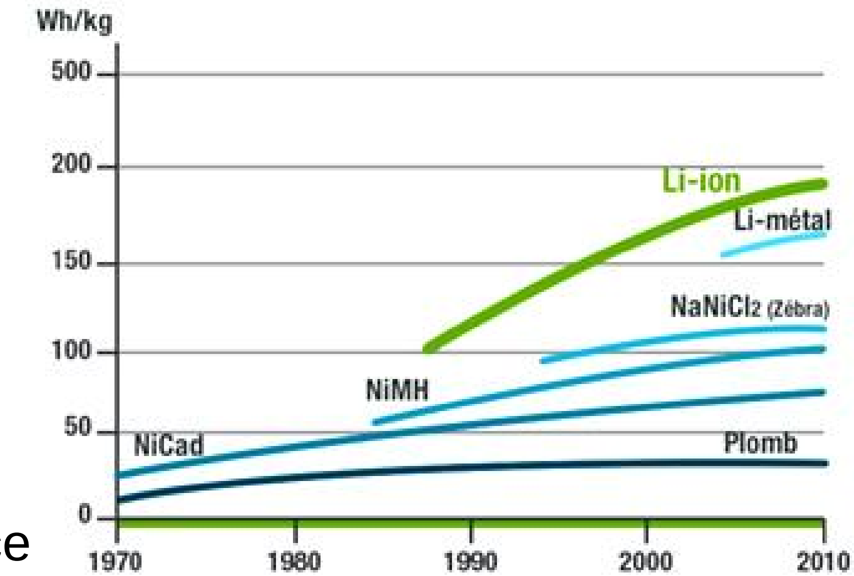
Research challenges

- How to increase robustness and fault tolerance of systems
  - Modulation methods to endure more interference
  - More efficient error correction and recovery
  - Better network architecture, including power feeding
  - More intelligent management and use of network resources
  - Security and vulnerability



Research challenges

- How to increase energy efficiency (of end-devices) when
  - Battery capacities grow slower than data rates and processing power
  - Processing can take place anywhere as all networked devices become a distributed software platform



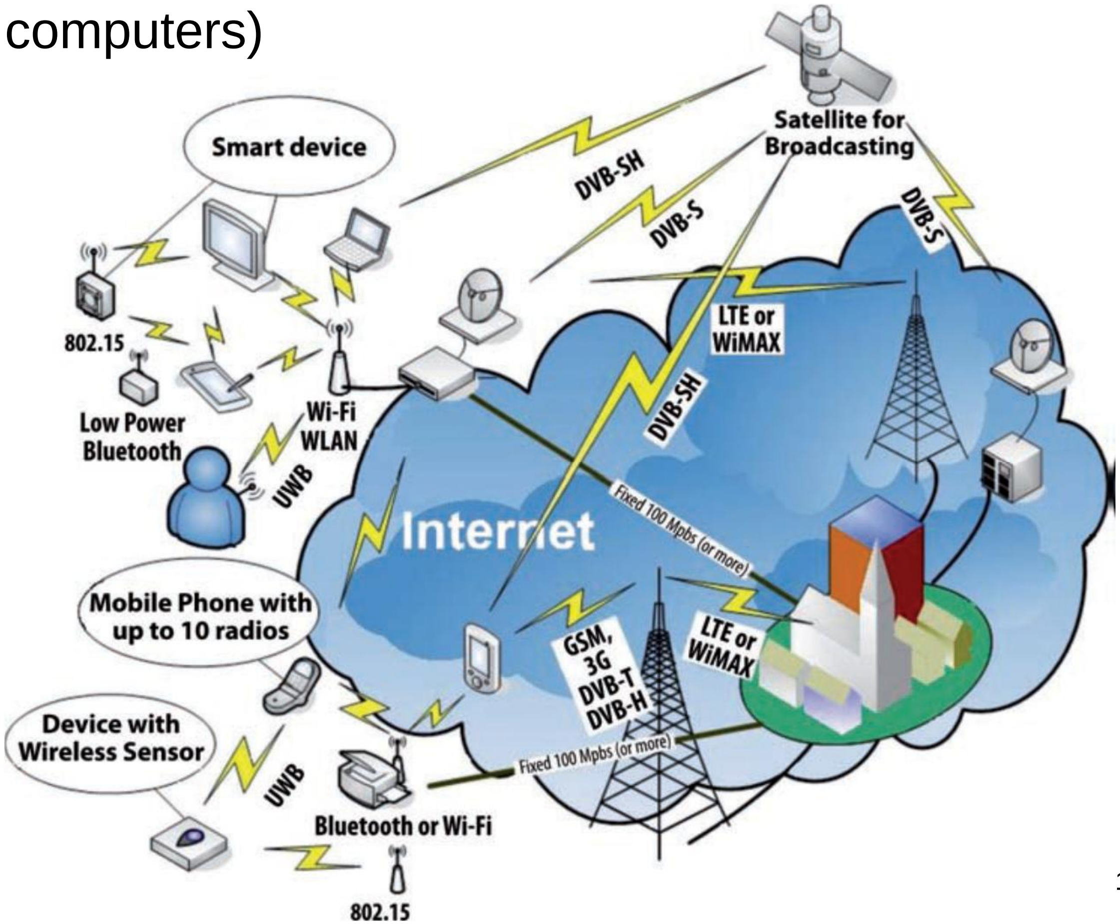
- How to manage distribution (of data)
  - Where should processing of data take place (locally at base stations or in network/cloud - low/high performance vs. low/high latency)
  - Predictable performance on heterogeneous devices
  - Security and thrust

Research directions and topics

- Network architectures
- Cognitive networking
- Network virtualization
- Autonomous network (control and management)
  - smart handovers
  - distributed decision making and reasoning
- Cognitive radio
  - Intelligent spectrum usage and sharing
  - Software defined radio and end devices

Evolving network architecture

- Integration of all sorts of access technologies
- Terminal devices with different capabilities (constrained sensors vs. full-scale computers)
- New networking paradigms (e.g. information centric networks and named data networks)
- Added mobility (incl. mobility of networks)
- Cognitive performance (e.g. self-organizing wireless mesh networks)



Internet architecture

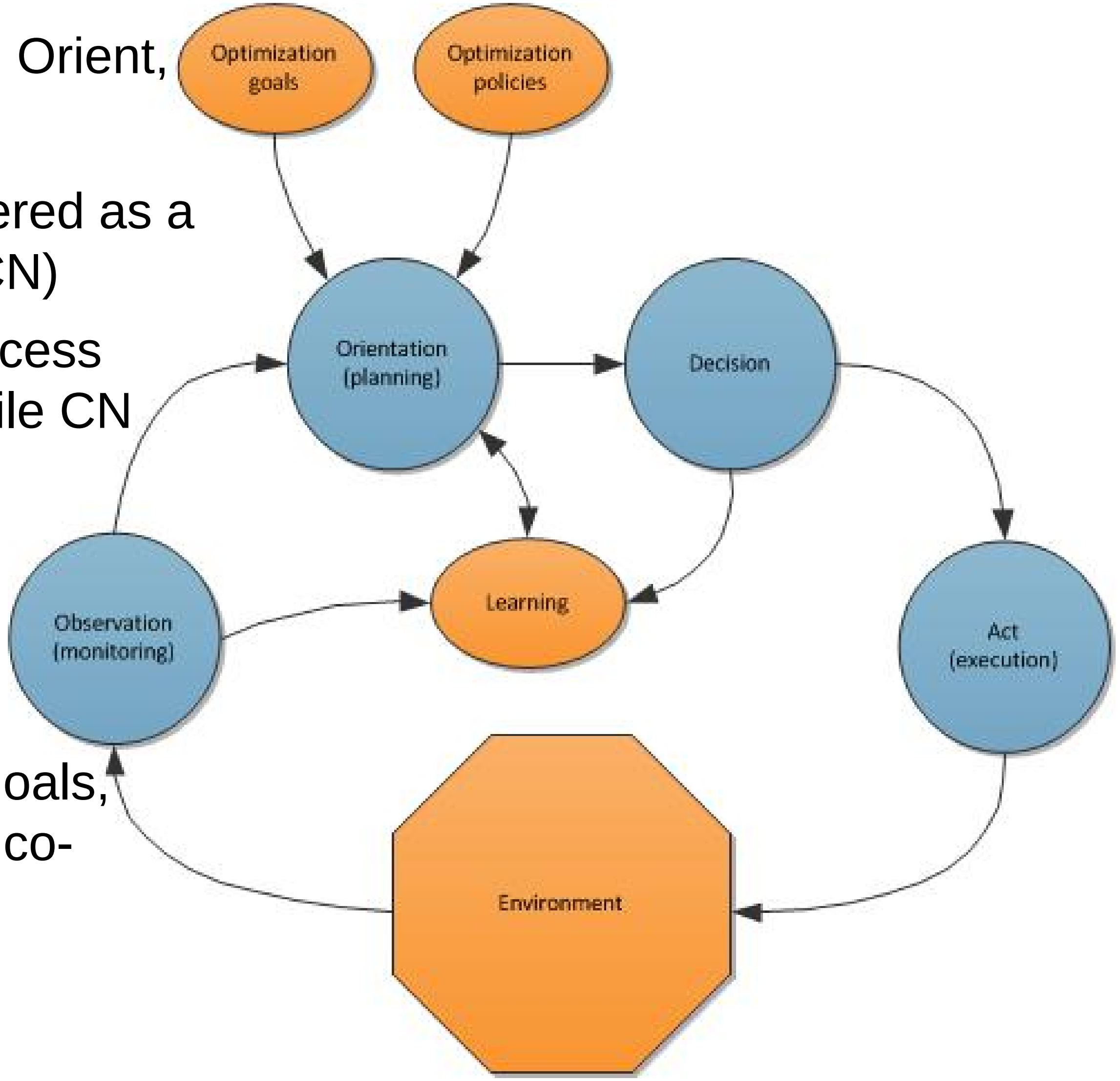
- The Internet architecture is starting to reach the limits of its remarkable ability to adapt and would need a fundamental overhaul:
  - Growth in traffic volume and interconnect devices
  - Impact of video and multimedia distribution
  - Energy consumption
  - Complexity and operational costs (OPEX)
  - Security, privacy and trust
- One of the current trends to overcome at least some of the problems is to go towards **perceivable, intelligent, self-managing autonomous networks**

Cognitive networking

- *"A cognitive network has a cognitive process that can perceive current network conditions, and decide and act on those conditions. Network can learn from these adaptations and use them to make decisions taking into account end-to-end goals."*
- Monitoring and observing the environment
  - Utilization of probes and agents
  - Measuring of network key performance indicators (KPIs), etc.
- Planning/orientation
  - Analysis of the situation and policies affecting the decision making, impact of previous decisions and acts, generation and evaluation of the alternatives
- Decision making
  - Actual decision making/hypothesis procedure - tightly coupled with orientation and actions
  - Implementation of decision making algorithms based on e.g. fuzzy logics, game theory, genetic algorithms, expert systems
- Execution/action
  - Execution of the system modifications and direct interaction with environment based on the decision making

Cognitive process in cognitive networks

- In principle an OODA loop (Observe, Orient, Decide and Act)
- Cognitive Radio (CR) can be considered as a special case of Cognitive Network (CN)
  - CR implements the cognitive process mainly at OSI layers 1 and 2, while CN considers the whole system
- Network system may implement several OODA loops in different system levels
- In order to fully achieve end-to-end goals, OODA loops need to be executed in co-operative manner



Virtualization of networks

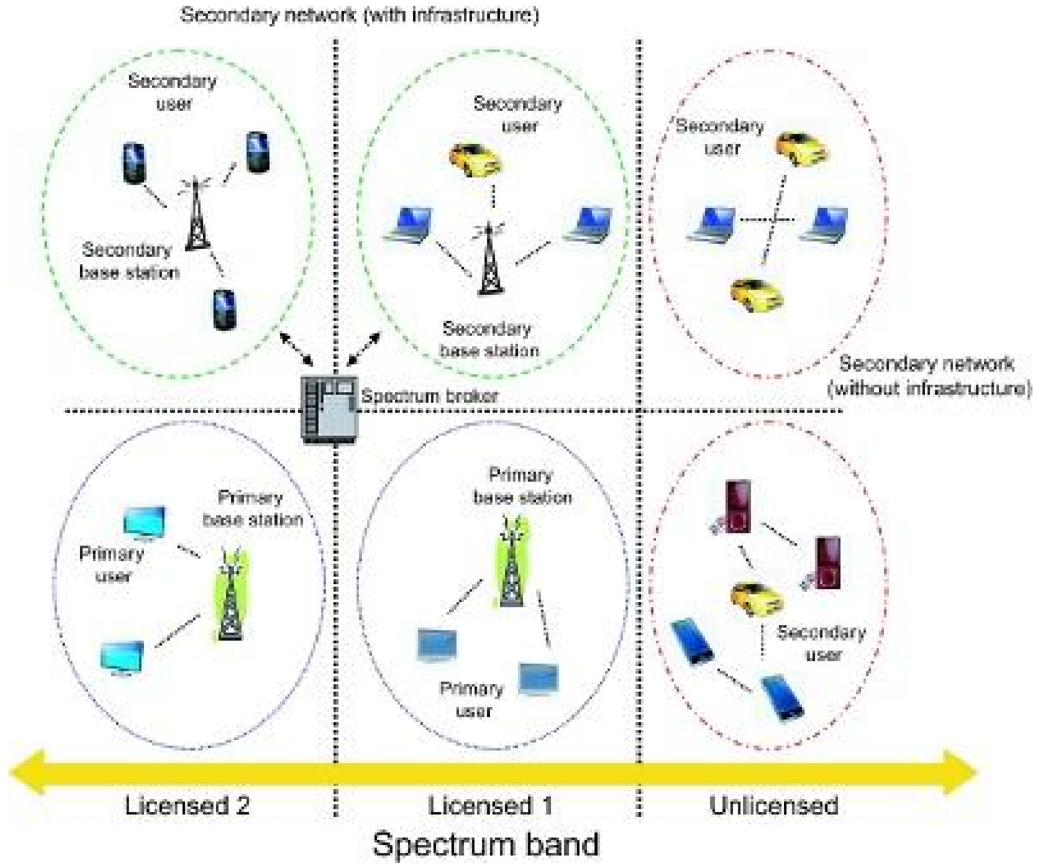
- Virtualization implies combining network's hardware and software resources and network functionality into a single, software-based administrative entity
  - common physical network infra (network elements, connectivity, storage, computation) divided by several operating parties
  - networking resources from different parties federated and shared
  - open interfaces provided
- Virtualization requires autonomous control and management functions from the network

Autonomous network

- An autonomous network is a network concept which requires little or no human intervention on its operation as it is capable of self regulating and managing
- Autonomous network is an intelligent network that includes capabilities such as self-configuration, self-heeling and self-optimization, and utilizes learning capabilities to be aware of its state and conditions
- Autonomous features developed to control and manage networks
  - Self-Organizing Networks (SON) and Software Defined Networks (SDN)
- IEFT GMPLS is one of the promising control plane architectures
  - GMPLS provides automatic provisioning of end-to-end connections with traffic engineering, traffic survivability (i.e. protections, restorations), automatic resource discovery and management
- Tomorrow network elements configure themselves
  - Network nodes communicate with other nodes to form a picture of the network and its conditions (topology, connections, QoS requirements, etc.) and configure its registers/parameters accordingly

Cognitive radio

- Intelligent radio that can be programmed and configured dynamically
- Transceivers designed to use the best wireless channels in their vicinity
- Radio automatically detects available channels in wireless spectrum and changes its transmission or reception parameters accordingly
- Concurrent wireless communications allowed in a given spectrum band at one location
- Dynamic spectrum management and sharing, e.g., based on ASA (Authorized Spectrum Access)

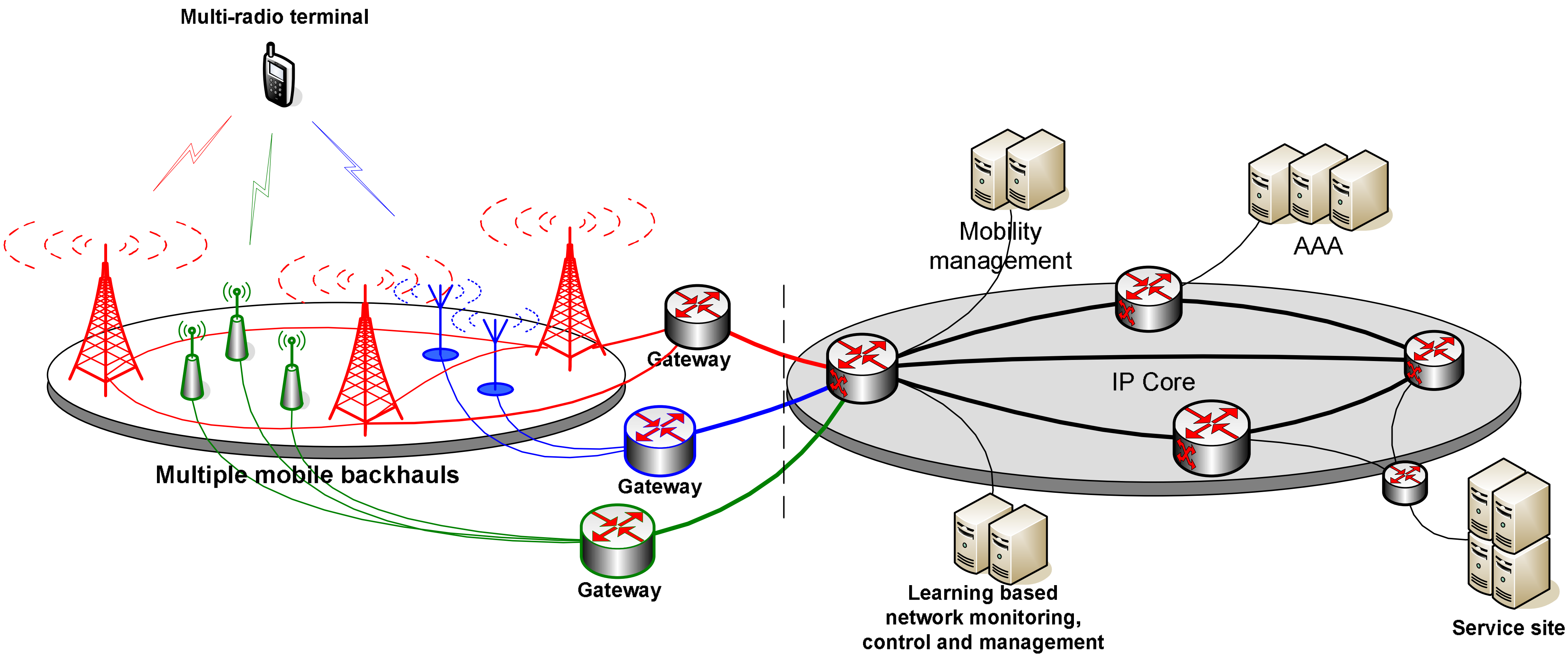


Examples of Future Internet research at VTT

1) Learning to support self-awareness and cognitive features of networks

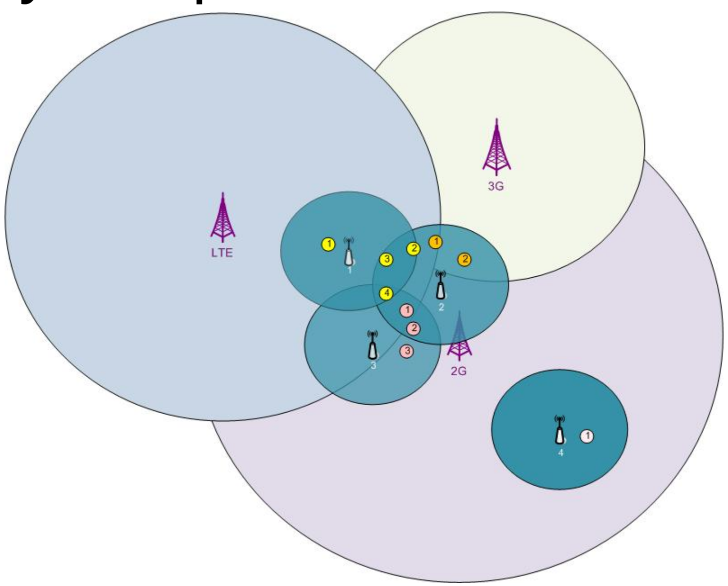
- Future networks will be very complex, virtualized and highly heterogeneous supporting different types of (radio) access technologies, services and users.
- Network operators are faced with the challenge of managing and maintaining overlapping networks of different (radio) access technologies.
- New types of communication (such as M2M) appears and this sets up new requirements for QoS, latency, reliability of connections, physical network management and configuration.

Multi-technology wireless networks



What to control and manage in multi-operator multi-technology networks

- Selection of access network
- Use of network resources (e.g. radio spectrum, routers and switches for capacity allocation or load balancing purposes)
- Quality of connections (e.g. bit rate, delay and packet loss rate)
- Services (e.g. video codec selection to adapt video to channel quality)



General problems to solve

- **Collection of network status information**
  - which status info to monitor and how to decide which of these are relevant in each network loading situation
  - how to collect status info effectively not loading the network too much
- **Processing of collected status information**
  - which algorithms to use in decision-making
  - too much processing causes too long decision-making delays
  - how to scale processing when networks get large

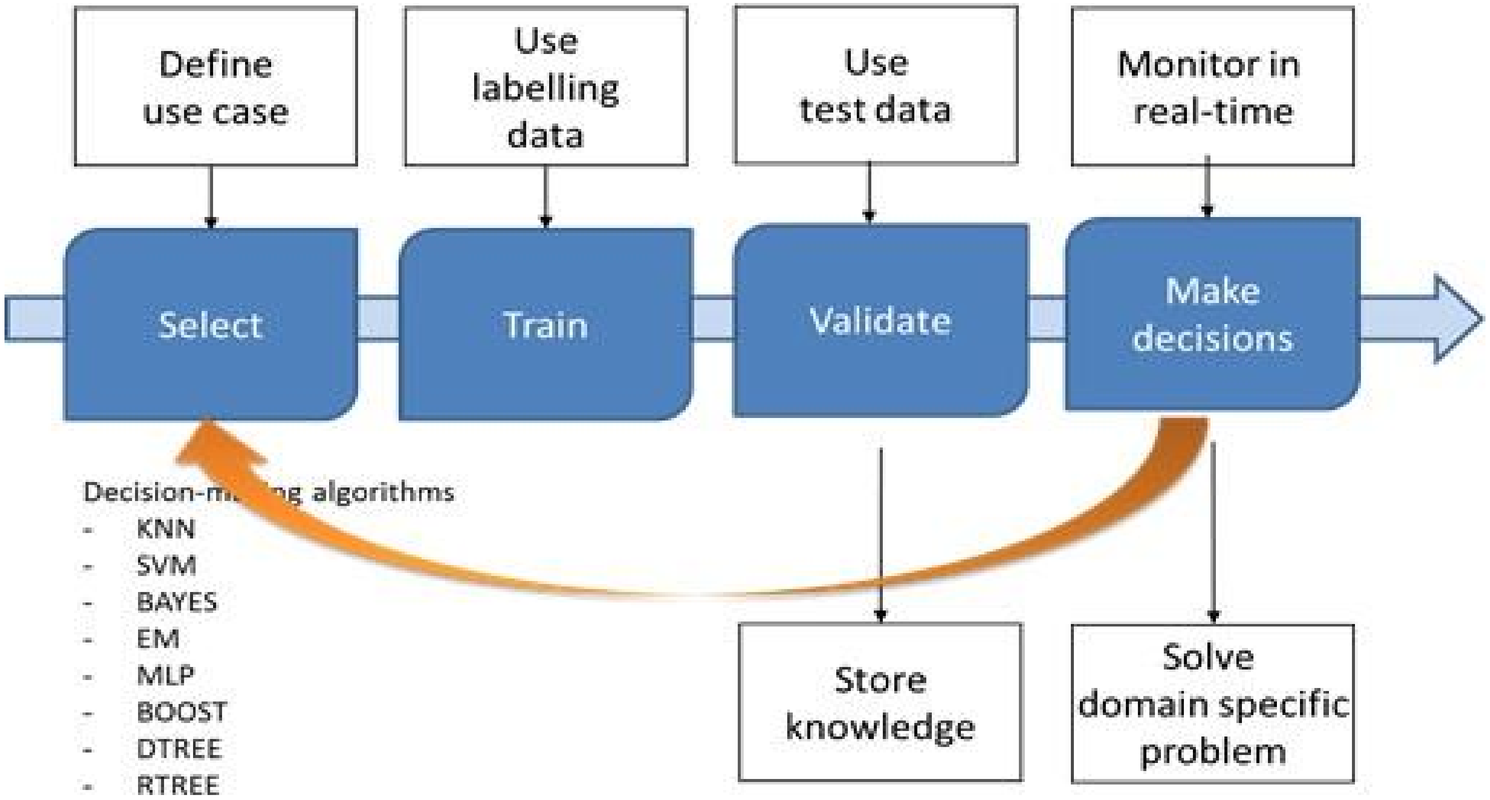
General problems to solve (cont.)

- **Signaling between networks and network entities**
  - ✓ signaling delays may be too long (to support real-time roaming)
  - ✓ signaling load may get too high thus lowering the throughput of networks
- **Actions to take**
  - ✓ when to redirect traffic, e.g. when to carry out intra-system handover or inter-system handover
  - ✓ when to terminate excessive traffic, e.g. connections and sessions that cannot get required QoS from the network
  - ✓ when to apply tightened connection admission control policy
  - ✓ what network elements and when to reconfigure

VTT's approach to learning networks

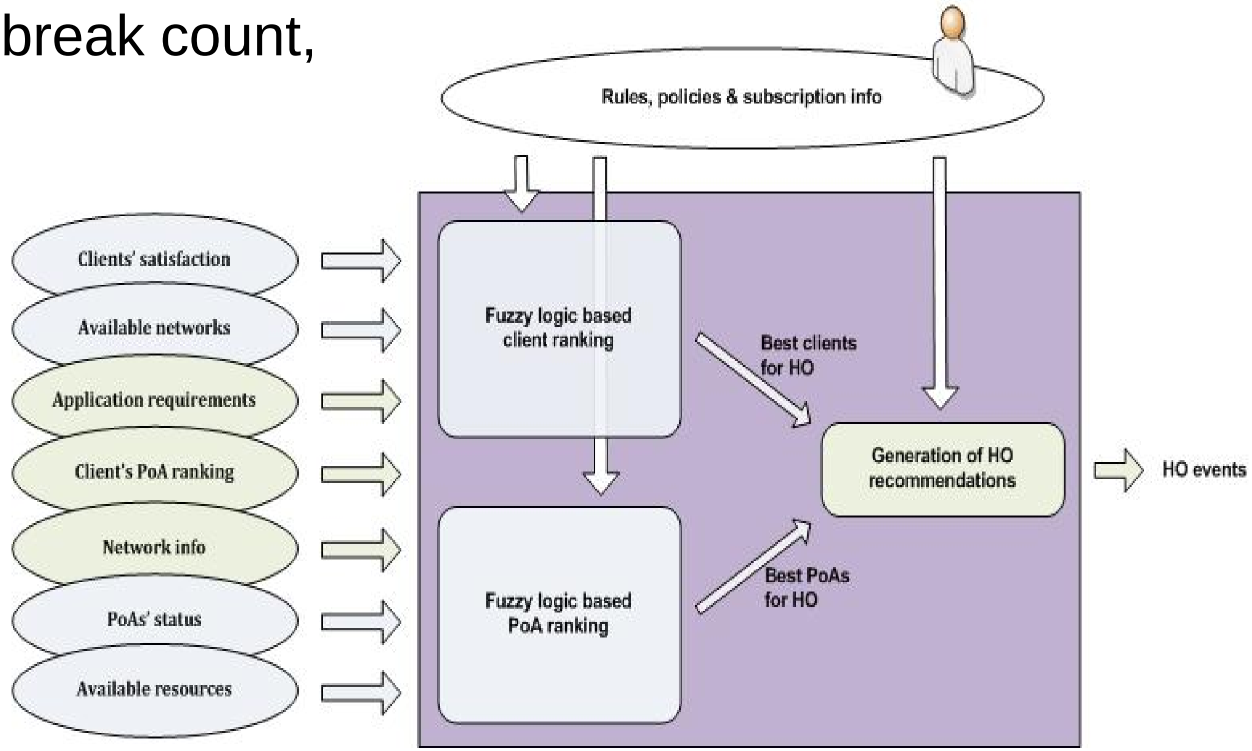
- Since 2007 VTT has been developing building blocks for a demonstration platform that utilizes real-time information from different sources.
- The information is used for decision-making to automate and optimize network operations, such as resource, vertical handover, mobility or QoS management in a more adaptive and proactive manner.
- The algorithm development has focused on
  - ✓ self-learning (e.g., Bayesian Networks, Fuzzy logic, K-means clustering, Q-learning, PCA and SOM)
  - ✓ vertical handover (IVHO = Intelligent Vertical HandOver)
  - ✓ adaptive video streaming
  - ✓ intelligent monitoring algorithms

Use of machine learning algorithms

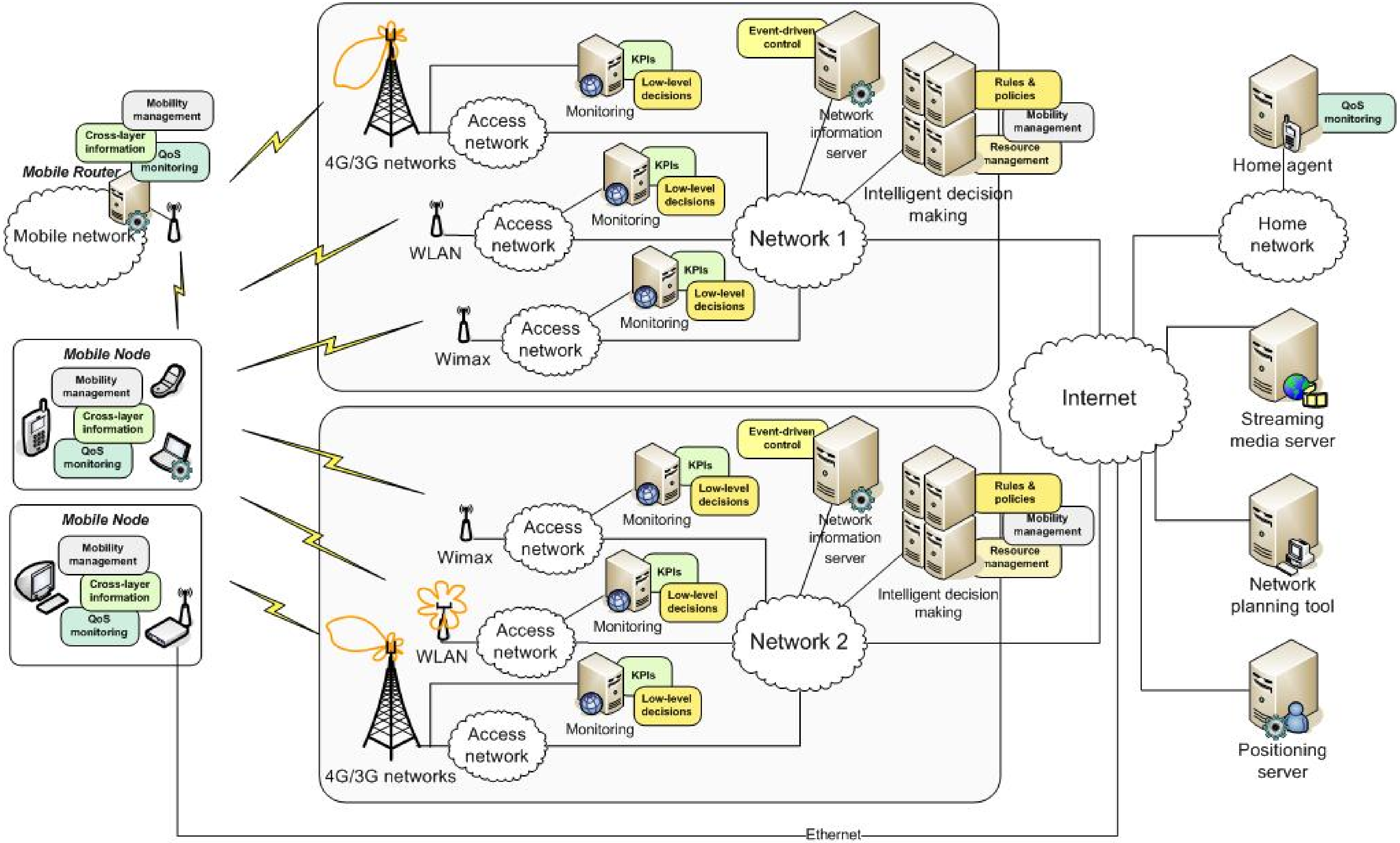


KPIs to monitor and manage

- ✓ Bit rates (especially aggregate bit rates per channel/bandwidth)
- ✓ Number of users per base-station and/or bandwidth
- ✓ Delay and delay jitter
- ✓ Packet loss rate, connection break count, connection break length
- ✓ Throughput and good-put
- ✓ Offered load
- ✓ SNR (Signal to Noise Ratio)
- ✓ RSSI (Reference Signal Strength Indicator)

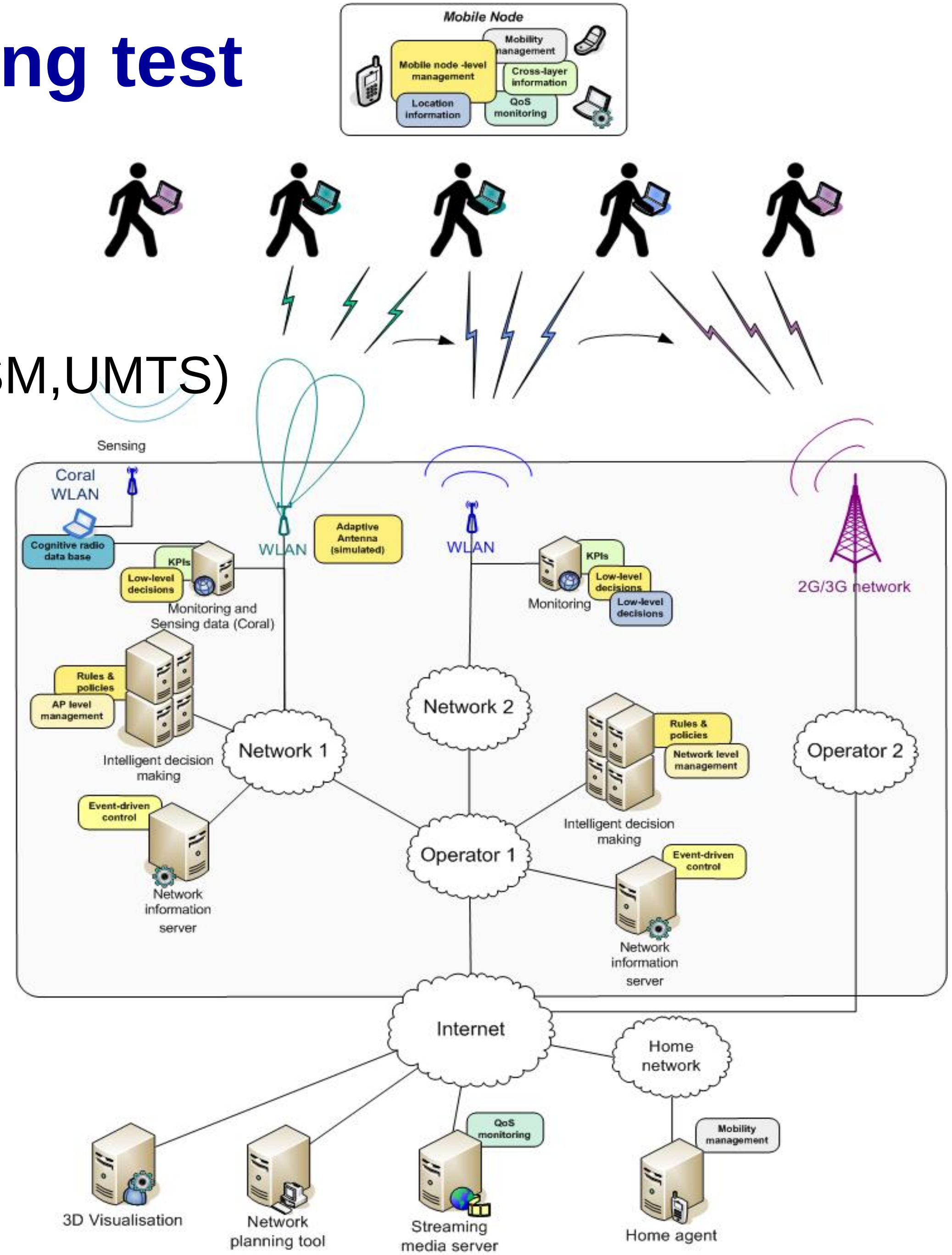


Framework for cognitive learning networks



Handover and video streaming test and demo platform

- Intelligent vertical handover (WLAN,GSM,UMTS)
- Intelligent Video streaming (WLAN)
- Testbed components:
  - ✓ **Terminal** – location and parameters
  - ✓ **QoSMeT** – application level QoS data
  - ✓ **NPT**- network planning information
  - ✓ **IVHO** – vertical handover commands
  - ✓ **Coral** – cognitive radio parameters
  - ✓ **3DVis** –virtual 3D simulator



Exploitation of QoS measurement information

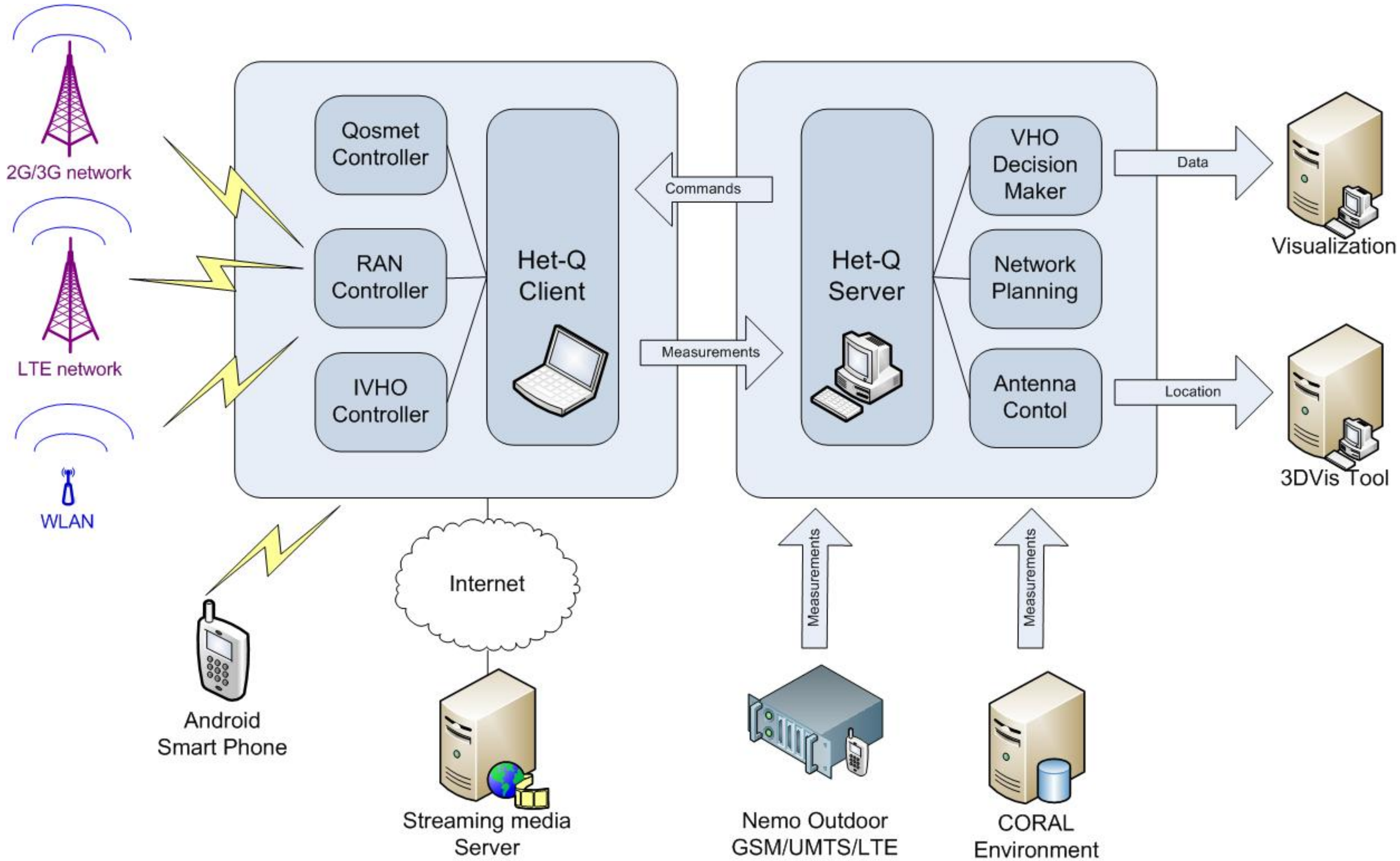
- Handover triggering to enable best possible connection at all times
  - ✓ Intra-system handovers
  - ✓ Inter-system handovers
- Traffic flow adaptation
  - ✓ for example adapting video traffic flows to degrading network conditions
- Congestion control management
  - ✓ offloading (e.g., between 3G and WiFi)
  - ✓ admission control

Developed measurement tools

- **Qosmet**
  - ✓ passive performance measurements and monitoring
  - ✓ measures one-way QoS performance from application's point of view in the selected network path

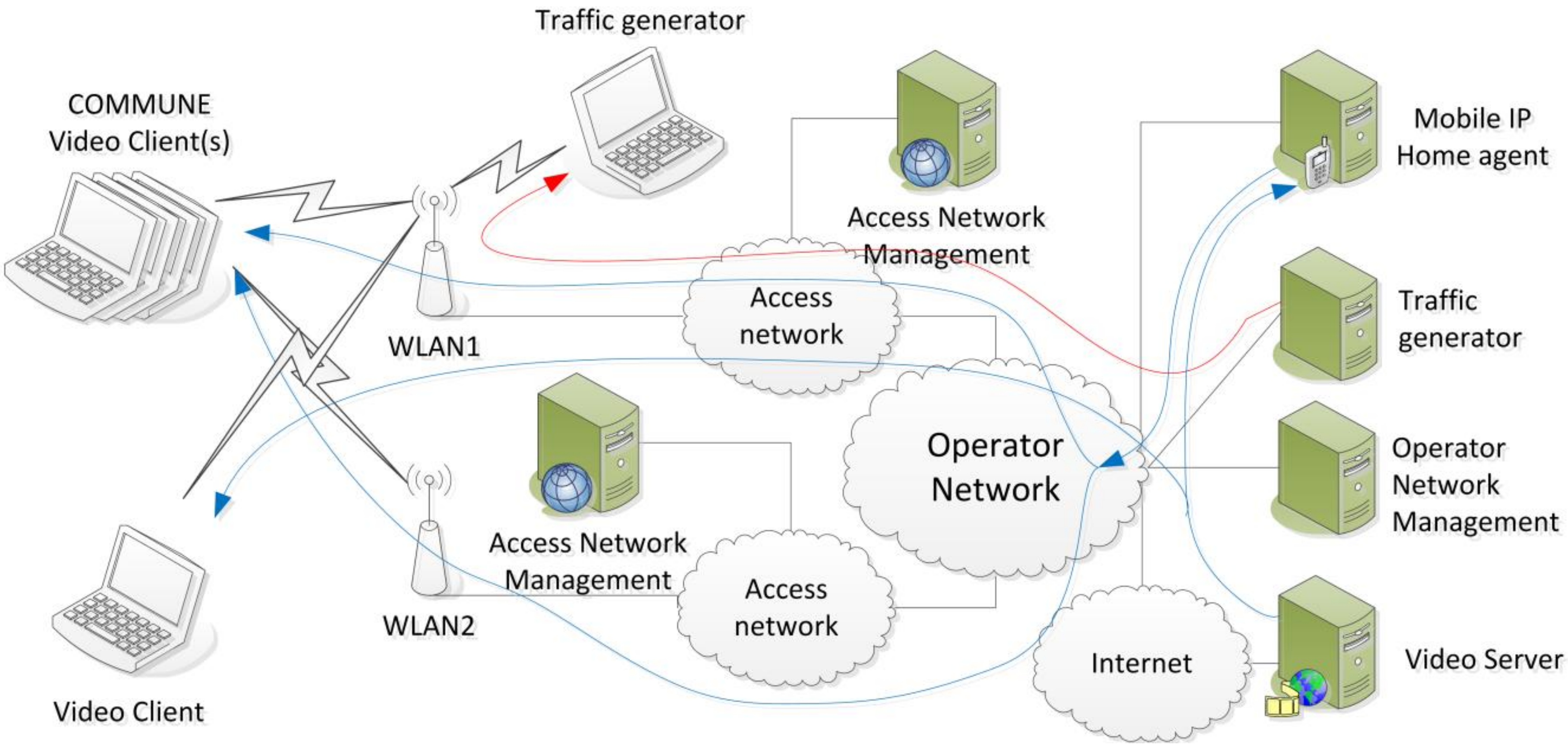
- **Moset**
  - ✓ active performance measurements and monitoring
  - ✓ multipoint measurements carried out by installing separate Moset instances in the network – measurement results of the instances integrated to get the whole picture of the monitored connection
- **Mobiilimittari**
  - ✓ a mobile phone application for measuring end-user's wireless broadband speed

Vertical handover testbed



Testbed for video QoE management

- Learning capability utilized in heterogeneous multi-access networks



2) Ad hoc and mesh networks

Challenges:

- Routing - multi-hop routing, multipath routing, multicasting
- Access control and authentication
- Transmission capacity, bandwidth and bandwidth allocation
- Radio signal propagation and interference
- Security
- Autonomic performance – self-organizing, self-administering, etc.
- Decision making algorithms
- Management of dynamic topology due to mobility
- Energy efficiency – selection of routes, lighter protocols (encryption and error correction) to lower processing requirement
- Scalability in many respects

Routing in ad hoc & mesh networks

- Must deal with limitations, such as power consumption, bandwidth, error rates and unpredictable movements of nodes
- **Pro-active** (table-driven)
  - Destination-Sequenced Distance Vector (DSDV) and Wireless Routing Protocol (WRP)
- **Re-active (source-initiated on-demand driven**
  - Cluster Based Routing Protocol (CBRP), Ad Hoc On-Demand Distance Vector (AODV) and Dynamic Source Routing (DSR)
- **Hybrid routing protocols, e.g. Zone Routing Protocol (ZRP) and Zone-based Hierarchical Link State (ZHLS)**
  - network partitioned into zones (each having a set of nodes
  - proactive approach used within each zone
  - reactive approach used between different zones
- **Multipath routing, solutions for multicasting**

Medium access control (MAC)

- ✓ MAC layer needs a (contention based or cooperative) mechanism to control access of single-hop (and multi-hop) flows to the medium in order to ensure each flow receives its entitled data rate.
- ✓ To achieve end-to-end fairness, network layer must inform MAC layer of the desired rate for each sub-flow
- ✓ Medium access control to support bandwidth allocation authentication

Bandwidth allocation

- ✓ Distributed bandwidth allocation algorithms are generally favored over centralized ones
- ✓ Key criteria for distributed algorithms are amount of data passed from node to node and convergence time and fairness
- ✓ Network layer is responsible for traffic flows and MAC layer for scheduling of transmissions
  - bandwidth allocation scheme must decide how these two layers interact

Bandwidth related problems

- ✓ Need for higher frequencies and better spatial spectral reuse
- ✓ QoS for ad hoc networks needed - no clear increase in link capacity to be expected due to bandwidth limitations
- ✓ Medium access control to support bandwidth allocation authentication
- ✓ Power (especially for battery-powered equipment) and bandwidth are precious resources
- ✓ Interference hard to deal with in changing radio propagation environment

Open problems in ad hoc & mesh networks

- ✓ **Autonomous control** - No centralized administration to manage operation of different mobile nodes
- ✓ **Dynamic topology** - Nodes are mobile and can be connected dynamically in an arbitrary manner. Network links vary timely and are based on distance between nodes.
- ✓ **Device discovery** – Identification of relevant newly moved in nodes and informing about their existence require dynamic update to facilitate automatic optimal route selection.
- ✓ **Bandwidth optimization** - Wireless links have significantly lower capacity than wired links.
- ✓ **Limited resources** - Mobile nodes rely on battery power, which is a scarce resource. Also storage capacity and power are severely limited.

Open problems in ad hoc & mesh networks (cont.)

- ✓ **Scalability** - Scalability can be broadly defined as whether the network is able to provide an acceptable level of service even in the presence of a large number of nodes.
- ✓ **Limited physical security** - Mobility implies higher security risks such as peer-to- peer network architecture or a shared wireless medium accessible to both legitimate network users and malicious attackers. Eavesdropping, spoofing and denial-of-service attacks should be considered.
- ✓ **Infrastructure-less and self-operated** - Self healing feature demands MANET should realign itself to blanket any node moving out of its range.

Open problems in ad hoc & mesh networks (cont.)

- ✓ **Poor Transmission Quality** - This is an inherent problem of wireless communication caused by several error sources that result in degradation of the received signal.
- ✓ **Ad hoc addressing** - Challenges in standard addressing scheme to be implemented.
- ✓ **Network configuration** - The whole MANET infrastructure is dynamic and is the reason for dynamic connection and disconnection of the variable links.
- ✓ **Topology maintenance** - Updating information of dynamic links among nodes in MANETs is a major challenge.

R&D examples of ad hoc and mesh networking

Self-organizing Wireless Mesh Network (WMN) for cellular backhauling

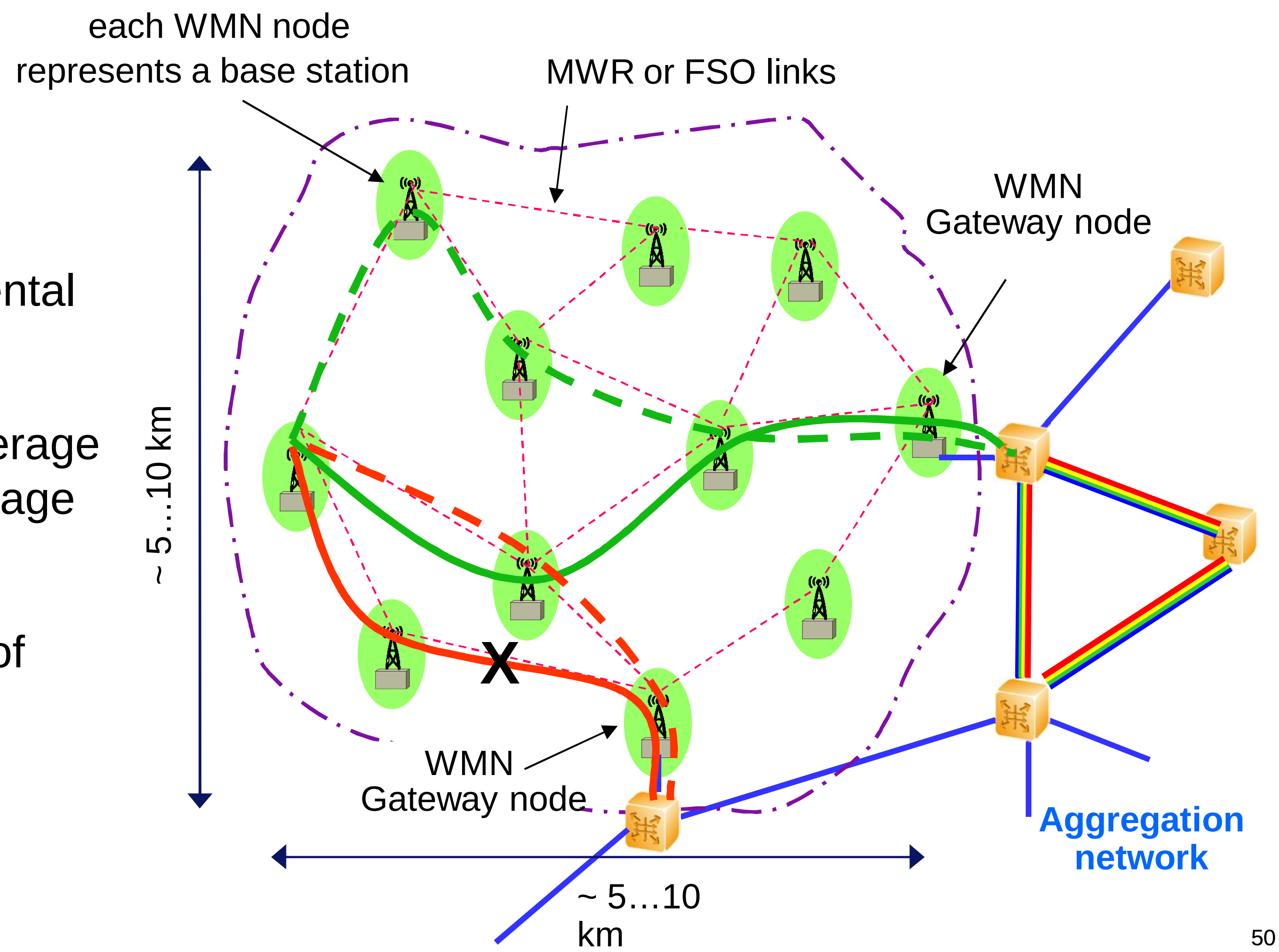
- In directional WMN concept, a set of client nodes (base stations) are connected together with point-to-point wireless links in a partial mesh topology.
- This group of nodes forms a WMN cloud, a self-organized routing area with dynamic traffic engineering capabilities.
- With in-built QoS aware routing and load balancing capability the WMN provides
  - ✓ automatic and transparent resiliency against failures
  - ✓ flexible use of available transport capacity in time-varying traffic load situations
  - ✓ guaranteed minimum capacity for high priority traffic even in extreme rain conditions.

Self-organizing Wireless Mesh Network (WMN) for cellular backhauling (cont.)

- WMN mesh topology can be adapted to different base station coverage scenarios: hierarchical and interleaved WMN clouds are supported to cover a wider geographical area and to support different transport needs.
- Typical cloud size is 20 – 30 base station sites, but up to 200 client nodes can be supported. The covered geographical area depends on the chosen link technology: wireless, Free-Space Optical, even wireline Ethernet, fibre or any mix of those are possible.
- Use of millimeter-wave point-to-point (PtP) radios allows very high capacity connections through the cloud and electrically steerable beam antennas enable easy and low cost deployment e.g. to walls, lamp posts, poles, etc.
- Each WMN cloud is connected to the external transport network via one or more WMN gateways.

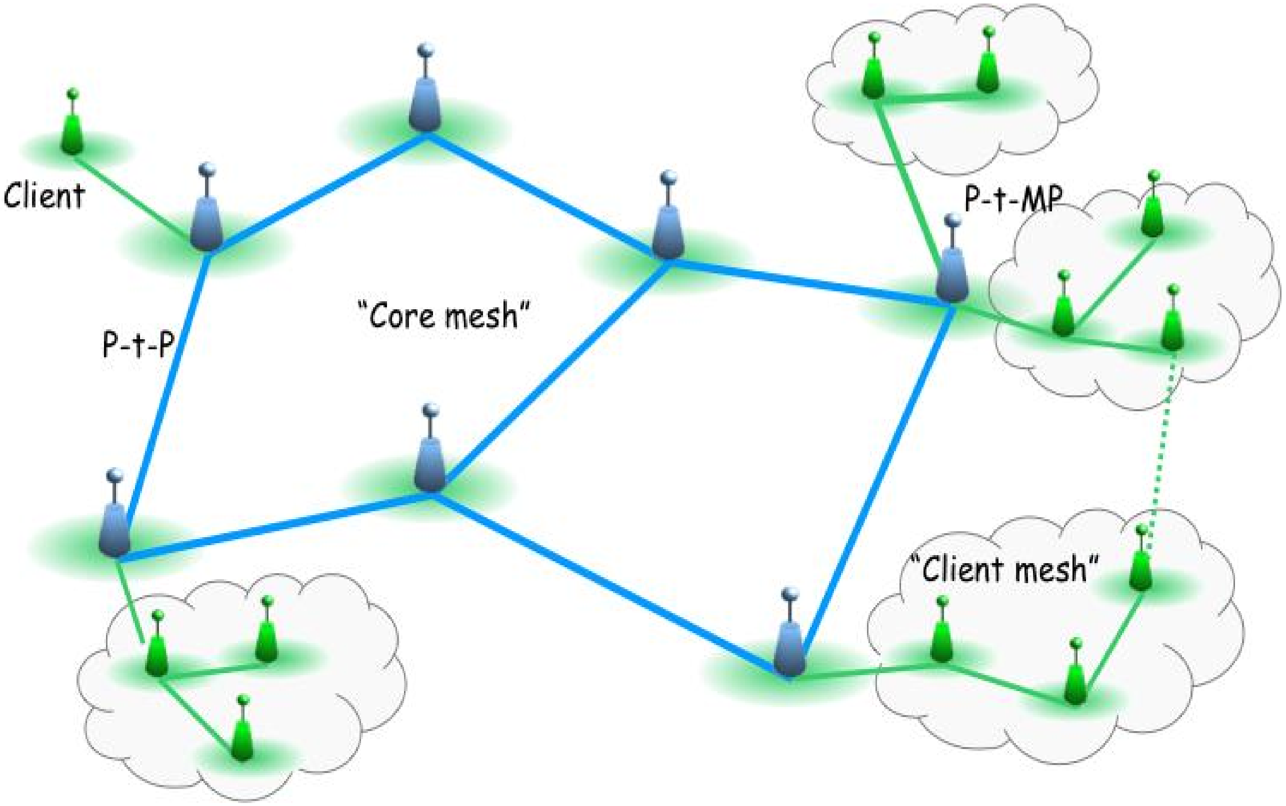
Microwave mesh backhaul

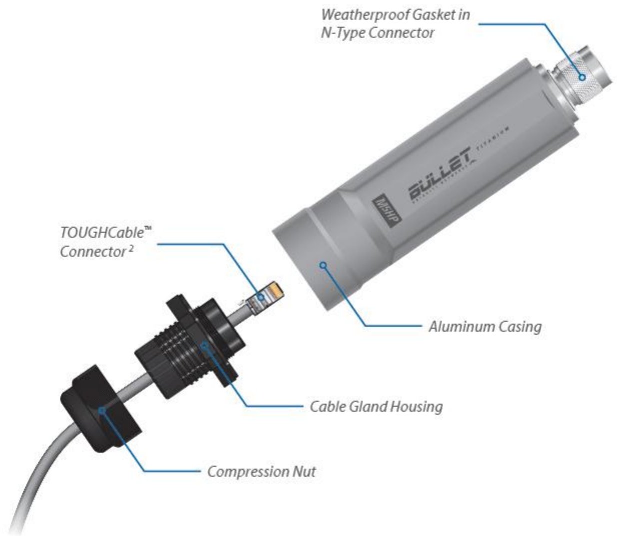
- Allows easy base station deployment and incremental network growth
- Brings capacity and coverage to hotspots where the usage of fibre is not feasible
- Enables load balancing of base station traffic



Low-cost long-range wireless mesh backhaul

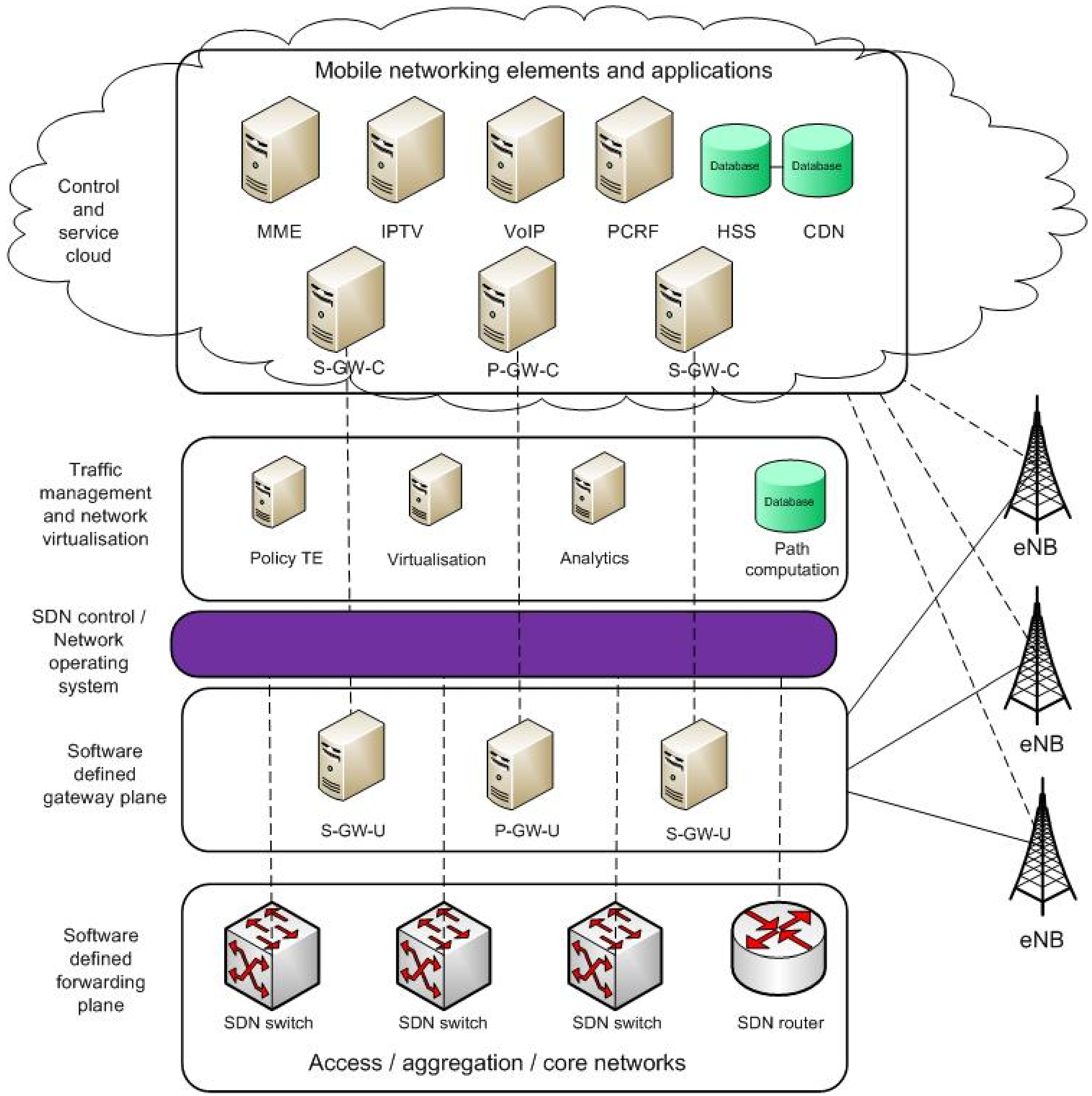
- Based on WiFi technology
- Brings coverage to the sparsely inhabited areas and to emerging regions
- Self-organising, energy-efficient, and robust operation



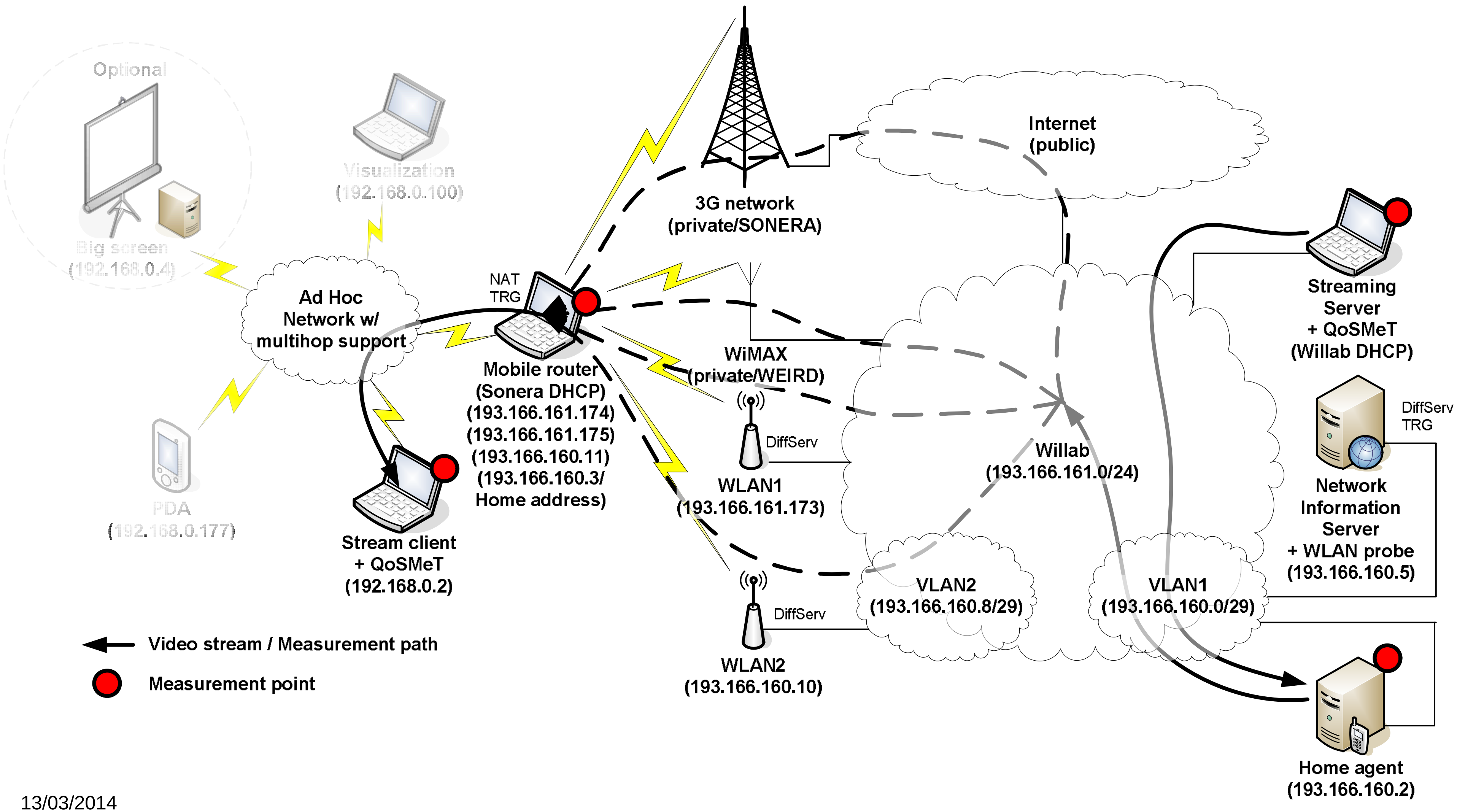


Software Defined Mobile Network

- SDN based control for forwarding and gateway planes
- Network virtualisation by slicing the network resources
- Cloudified control and service elements

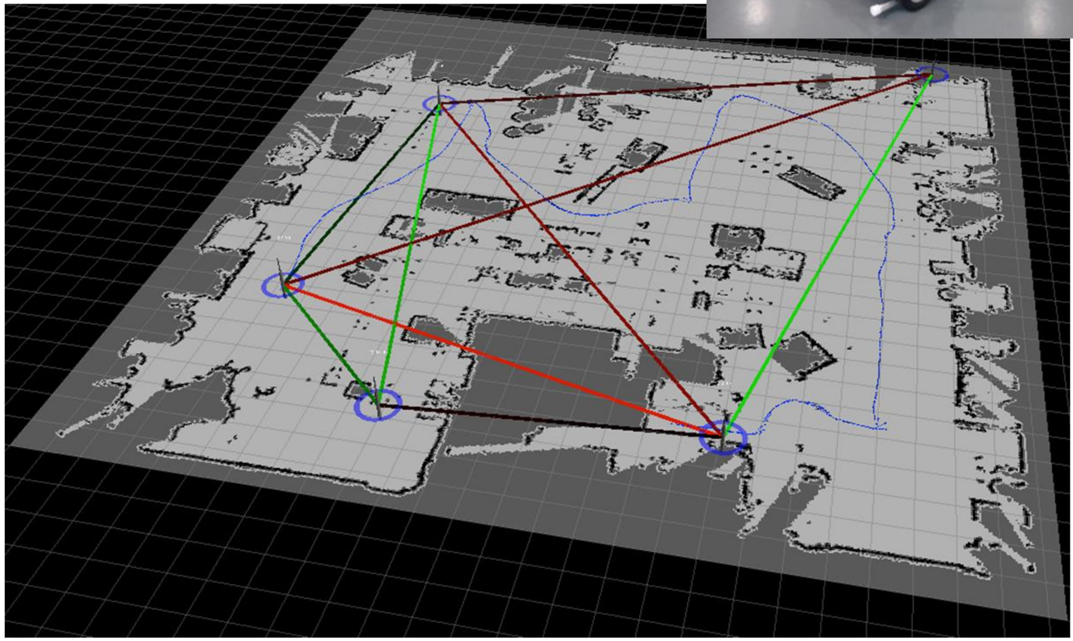


Platform for ad hoc and personal networks, mobility and multi-access scenario



Automatic data collection using mesh networks

- Collection of live data from environments that do not have network infrastructure
- Solution is based on 5GHz Wi-Fi and B.A.T.M.A.N. protocol
- Each mobile robot is equipped with a mesh node
- Static nodes can be installed easily on demand (no backbone network required)
- Solution provides mobility with high speed connectivity
- Mobile robots can be used to extend wireless network into a new area not covered by static mesh nodes



Mesh network links in a warehouse trial


TECHNOLOGY FOR BUSINESS