Mobile Communications Networks

– Evolving through Biologically-Inspired Technologies –

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Mobile Communication Networks

- Mobile communications networks are getting more and more complex with
  - Variety of services they offer
  - Variety of devices connected to the network
  - Variety of environment and channel conditions they work in
  - Variety of possible interconnections they have to make
  - and more recently, variety of network topologies they can use

Communications Technologies

- Emergence of several access technologies has resulted in a multitude of heterogeneous systems targeting different service types, data rates, and users
  - 1G to 2G migration: A transition from analog to digital
  - 2G to 3G evolution: Popularity of Internet and need for higher mobile data rates
  - Complementing service from several access technologies:
    - Cellular: 2G (GSM and IS-95), 3G (UMTS and cdma2000)
    - High speed data networks: IEEE 802.11, HiperLAN
    - WiMAX, Mobile WiMAX, MobileFi, …
    - Digital broadcasting systems: DAB, DVB, DMB
- The missing bit
  - A single architecture to integrate all these and future systems, enabling users to have global reliable connectivity

Main Motivations for NGMN

- Demand for better availability of services and applications
- Global connectivity for any-type services at anytime, anywhere and anyhow
- Rapid increase in the number of wireless subscribers who want to make use of the same handheld terminal while roaming
- Support for bandwidth intensive applications such as real-time multimedia, online games and videoconferencing as well as traditional voice service (e.g., through VoIP)
- The scalable and distributed next generation mobile network architecture is expected to offer any-type services over a diverse set of indoor, outdoor, pedestrian, and vehicular
- These services will be offered over a large range of overlapping access networks that offer different data rates, coverage, bandwidth, delay and loss, and other QoS requirements

Universal Ubiquitous Coverage

- Universal ubiquitous coverage across different radio technologies is the ultimate objective of the future mobile networks
  - Answering the increasing demand for higher transmission rates and flexible access to diverse services
  - Offering a rich range of services with variable bandwidth and service quality
  - Satisfying users' mobility and traffic service requirements
  - Covering different geographic areas and accessing to different types of service
- The universal ubiquitous coverage need to be realized through
  - Connectivity across multiple networks
  - Interoperability across different radio technologies

Next Generation Mobile Network

- To offer an integrated system
- To promote interoperability among networks
- To offer global coverage and seamless mobility
- To enable the use of a universal handheld terminal
- To enhance service quality compared to current wired networks

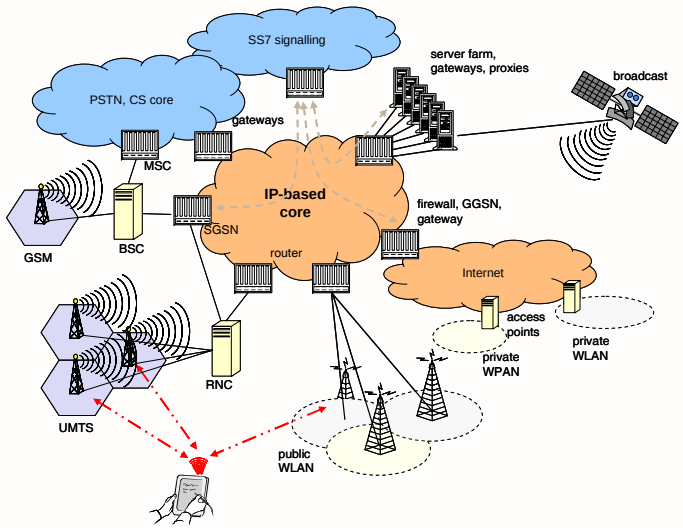
ITU Recommendations

NGMN to:

- be an open system
- be an access-independent to underlying transport technologies
- be an access-independent with service oriented functionalities
- include seamless mobility across networks
- aim toward providing a guaranteed end-to-end service quality

Next Generation Mobile Network

NGMN will be an integrated platform interconnecting multiple networks for seamless user connectivity for multimedia applications anytime and anywhere



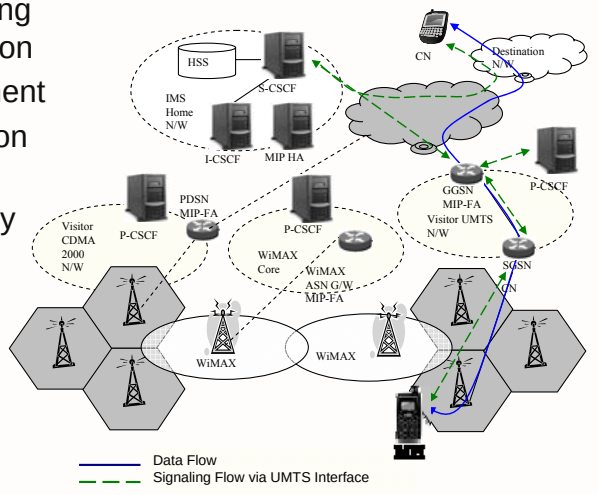
It is the ultimate solution to the problem of ubiquitous mobile communications!

Heterogeneous Mobile Technologies

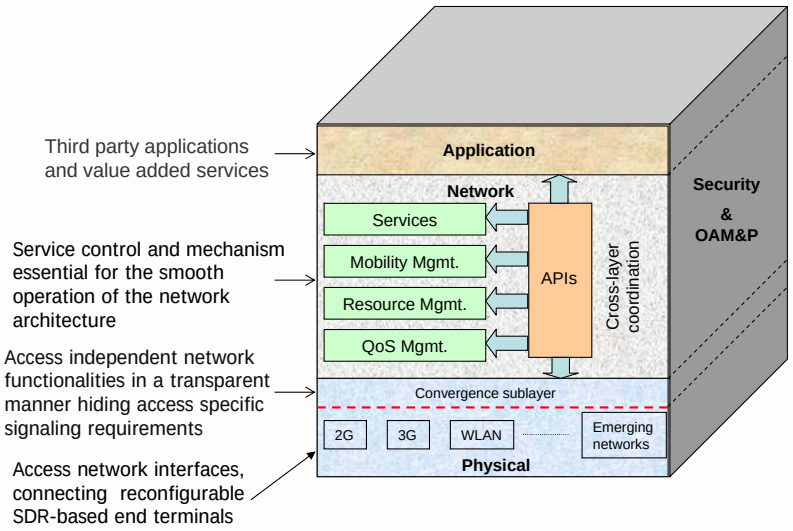
- Communication networks differ based on their
  - Air interface and spectrum requirements
  - Offered services
  - Data rates and QoS requirements
  - Modulation and coding scheme
  - Core network functionalities
  - Signaling requirements between terminal and network
- Service across other networks is not guaranteed
  - Lack of interoperability
  - Lack of service agreement
- Users require
  - Different handheld terminals
  - Separate subscriptions

Networking Issues in NGMN

- Internetworked routing and address allocation
- Resource management
- Traffic and congestion control
- Mobility among many networks
- Network address translation
- Network protocol translation



Complex NGMN Design



NGMN System Requirements

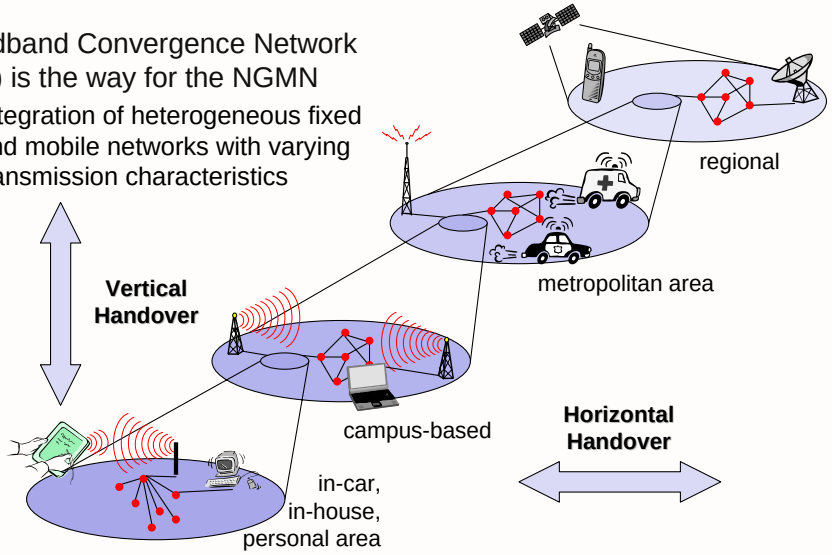
- Architecture supporting heterogeneous networks
- Adaptive protocol stack
- Enhanced mobility management addressing different handoffs
- Enhanced RRM techniques to admit horizontal and vertical handoffs

Open Design Issues

- Adaptive NGMN Architecture
- Cross layer coordination
- Vertical handoff
- Call admission control
- Mobile terminal

Broadband Convergence Network

- Broadband Convergence Network (BcN) is the way for the NGMN
  - Integration of heterogeneous fixed and mobile networks with varying transmission characteristics

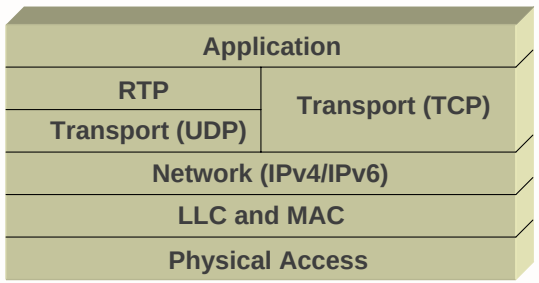


NGMN's Inter-Domain Service

- Service transition from fixed domain into mobile domain and vice versa *seamlessly*
- No sensible change of service quality received by a user while moving from a fixed domain into a mobile domain
  - Fixed-to-mobile or mobile-to-fix domain
  - From one mobile network to another mobile network
- Service independency to the radio access technology
  - No dramatic change in QoS particularly in data rate (i.e., the most humanly sensible quality measure)
  - Logically followed by the delay requirement
- Such service availability will need modifications at all layers of the network protocol stack
- A system of authentication and authorization that supports access across different network is also needed

IP Architecture

- If we agree on the assumption that IP will be the core part of the next generation mobile networks, then the traditional protocol architecture seems to be inadequate
  - A modular architecture designed based on stack of protocols
    - Using services provided by the lower module
    - Providing new services to the upper layers
      - Communications mainly between adjacent layers



IP Architecture – Conventional

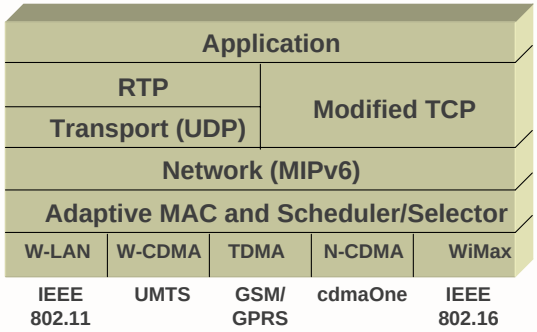
- Link layer (e.g. Ethernet): Providing connectivity to other network segments; i.e. not to hosts in different networks
- Network layer (e.g. IP): Delivering datagram packets across multiple networks
- Transport layer
  - TCP: Providing connection-oriented communication services, making communication reliable, avoiding network congestion
  - UDP: Providing simple and unreliable transport for quicker communications (required for real-time applications)
- Where to put the main elements necessary for NGMN?
  - *QoS:* So that IP network could be used for voice, video, and other multimedia real-time services
  - *Mobility:* Among APs of the same technology (micro-mobility) or across networks of different technologies (macro-mobility)

NGMN Protocols Re-Design Need

- Physical layer
  - Multiple physical network interfaces (cellular, W-LAN, WiMax, …)
- Link layer
  - Establishment of concurrent connections via different access networks
  - Packet scheduling and optimum network selection mechanisms
- Network layer
  - Accommodating mobility in IP protocol
  - Faster and easier routing techniques with less signaling
  - IP global (and heterogeneous) address translations
- Transport layer
  - More wireless friendly transport protocols (than TCP and UDP)
- Application layer
  - Management of optimum compression and data rate control

IP Architecture – Modified

- Adding mobility features at network layer
- Increasing address space and easing routing at IP layer
- Modifying TCP for better performance at high error rate environments (e.g. over wireless channel)
- Additional sub-layers for adaptive selection of a network and associated MAC protocol



Protocol Stack Enhancement

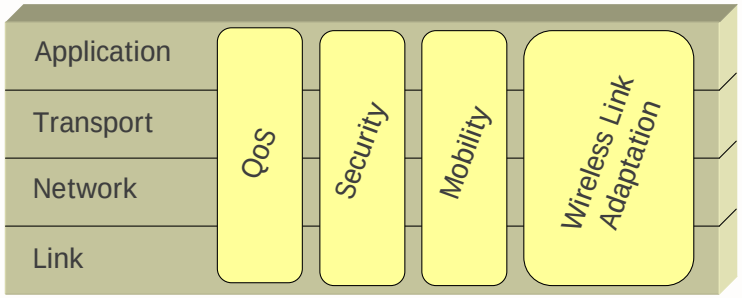
- Modifications of individual layer protocols so that the overall architecture can handle the heterogeneity
  - Example: The AdaptNet
- Modification of overall protocol stack, removing the modularity character from it and allowing interaction of protocol layers with layers other than the adjacent one
  - Example: The Cross-Layer architecture design

AdaptNet

- Making link, transport, and application layers adaptive (not changing the network layer) at *mobile host*
- Also inclusion of some cross-layer interactions
- Application layer
  - Handling data and bit error rate fluctuations of the wireless channel by means of adaptive source and channel coding
- Transport layer
  - Use of an adaptive mobile-host-centric transport protocol called Radial Reception Control Protocol
- Link layer
  - Use of an adaptive MAC for seamless medium access control over heterogeneous networks
  - Use of an adaptive error correction scheme which changes the coding rate in accordance with the channel condition

Cross-Layer Architecture Design

- Concept: By leaving protocol stack strictly modular, it will be inefficient with respect to performance, QoS, and energy consumption, etc.
- Solution: Proving information from non-adjacent layers in a cross-layer structure



Coordination Planes

- Four separate *vertical planes* that coordinate the information exchange and actions to be done by individual layer protocols

- **QoS:** For distribution of QoS requirements and constraints and coordination of efforts by layers to achieve QoS
- **Security:** For elimination of encryption duplication at several layers
- **Mobility:** Enhancing interactions among TCP, IP, and link layers in handling mobility in different environments
- **Wireless Link Adaptation:** Providing adaptive bit error rate and data rate depending on different wireless channel conditions and different mobile environment

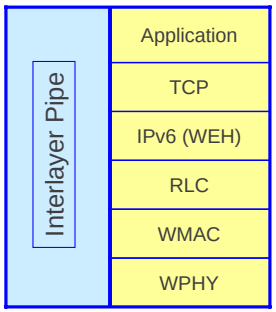
Cross-Layer Coordination

- Cross-layer coordination between different entities within the architecture would be necessary in NGMN
  - For wireless system discovery to provide a list of access networks and their associated QoS parameters
  - To support QoS enabled application, direct communication between application layer and QoS sub-layer are essential
  - To provide services in a visited network based on service policy and subscriber profiles signaling between mobility management sub-layer and services sub-layer as well as between services sub-layer with resource management and QoS management sub-layer are essential
  - When service is no more possible after a vertical handover
  - Also for accounting purpose using information related to the resources used, QoS provided, time and duration of provision of network resources, etc

Cross-Layer Coordination Methods

Interlayer Signaling Pipe (ISP) Approach

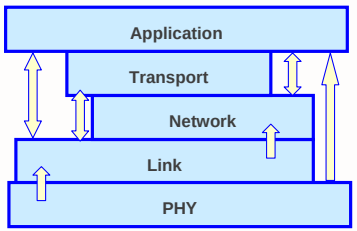
Cross-layer information (TCP/RLP related) are stored in the wireless extension header (WEH)



- Interlayer Pipe passes through all layers
- Suffers from longer processing delay

Direct Connectivity Approach

- Direct connectivity among non-adjacent layers
- Separate definition of APIs

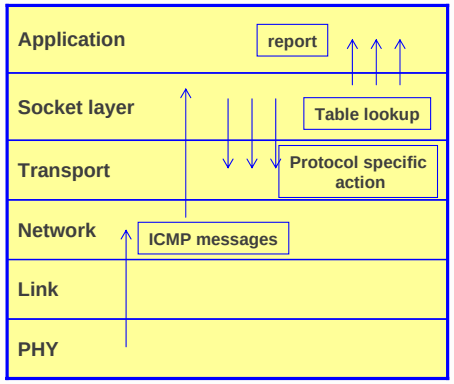


- How controllable QoS parameters form individual layers translate into parametric quantities?
- How to optimize the decision process?

Cross-Layer Coordination Methods

ICMP Approach

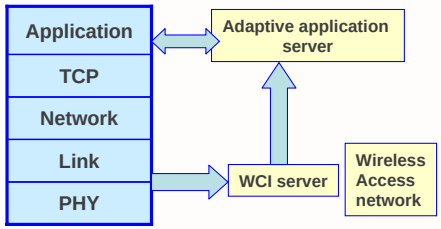
Use of watermark based mechanisms to initiate ICMP messages whenever network conditions change



- Suffers from longer processing delay

Ad Hoc Network Approach

Information exchange through external servers



- May not be suitable for time-critical applications

Cross-Layer Coordination Views

- Cross-layer coordination not yet standardized
- Room for contributions
- Will be key to offering enhanced services
- Mainly confined to the network level functionalities
- Therefore concentric to the network layer in the proposed system model

Broadband Wireless Internet

- Implementation of a true Broadband Wireless IP requires an efficient integration of heterogeneous BcN elements
- The path toward Broadband Wireless IP therefore crosses multiple networks with heterogeneous characteristics consisting of several technologies with multiple configurations consisting of
  - **Cellular based networks (centralized)**
  - **Ad hoc networks (decentralized)**
  - **Mesh networks (mixed centralized-decentralized)**

Different Topologies

- Cellular
  - In line with current infrastructure and coverage
- Ad hoc networks
  - Distribution of responsibilities of network elements
  - To add coverage, capacity, and new services for example through vehicular communications (VANET)
- Wireless Mesh networks
  - In appose to the existing star topology of cellular networks
  - The main limitations of a wireless network is high level of transmission power and multipath transmission
  - Wireless mesh network can remove those limits through
    - Covering short range, so low power transmission
    - No ugly towers
    - Mostly LoS, so no multipath transmission problem

Challenges

- Too much of complexity in the heterogeneous network
- Resource management of multiple interconnected networks and their topology creation
- Traffic management and load balancing/sharing among heterogeneous mobile and fixed networks
- Network optimization, organization of efficient interconnection, and incorporation among multiple networks

Biological systems may give some hints toward dealing with these challenges …

Why Seek Inspiration from Biology?

- Living organisms are *complex adaptive systems*
  - Artificial systems are going in that direction too
- Look for *new solutions* to difficult problems
- Life has many *self-** features which are also desirable in artificial systems:
  - Self-organization
  - Self-adaptation
  - Self-healing ability
  - Self-optimization
  - Self-robustness

NGMN and Biological Systems

- Heterogeneous networking technologies, devices, and services keep changing in NGMN over the time
  - A centralized control/management tends to be an infeasible approach for NGMN
- The dynamic NGMN architecture and protocols need to have
  - scalability, self-organization, self-adaptation, and sustainability
- By appropriately mapping key biological principles to NGMN architectures it is possible to create a scalable, self-organizable, self-adaptable, and sustainable network
  - Such network is motivated by the inspirations from various biological systems' abilities to naturally adapt to the changing environment

The Term "Bio-Inspired"

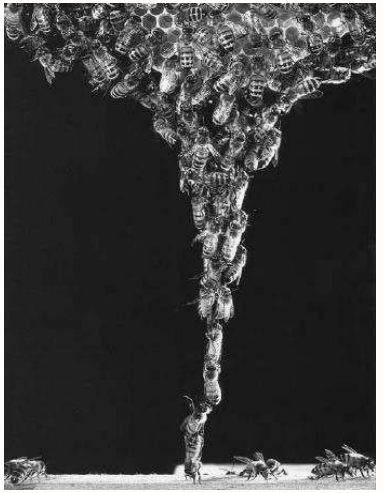
- ***Bio-inspired*** demonstrates the strong relation between
  - A particular system or algorithm
    - which has been proposed to solve a specific problem
  - And a biological system
    - which follows a similar procedure or has similar capabilities
- Bio-inspired computing represents a class of algorithms focusing on efficient computing
  - e.g. in optimization processes and pattern recognition
- Bio-inspired systems rely on system architectures for massively distributed and collaborative systems
  - e.g. in distributed sensing and exploration
- Bio-inspired networking is a class of strategies for efficient and scalable networking under uncertain conditions
  - e.g. in delay tolerant networking

Biologically Inspired Problem Solving

- Typical problems that can be tackled with bio-inspired solutions are characterized by the:
  - Absence of a complete mathematical model
  - Large number of (inter-dependent) variables
  - Non-linearity
  - Combinatorial or extremely vast solution space

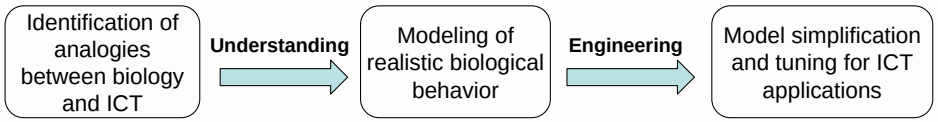
Why Bio-Inspired Networking?

- Structural view: communication is an intrinsic part of an organization
- Example organizations:
  - Brain (organization of neurons)
  - Animal "super organisms" (ant/bee colonies)
  - Human society
- Those natural and living organizations seem better organized than the current Internet!



Design of Bio-Inspired Solutions

- Identification of analogies
  - In swarm or molecular biology and ICT systems
- Understanding
  - Computer modeling of realistic biological behavior
- Engineering
  - Model simplification and tuning for ICT applications

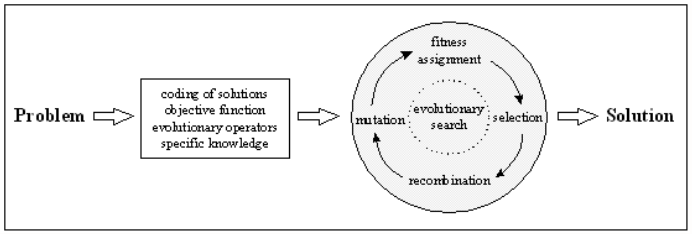


Example of Bio-Inspired Research Fields

- Evolutionary Algorithms (EAs)
- Artificial Neural Networks (ANNs)
- Swarm Intelligence (SI)
- Artificial Immune System (AIS)
- Cellular Signaling Pathways

Evolutionary Algorithms (EAs)

- Mainly rooted on the Darwinian theory of evolution
- An EA uses some mechanisms inspired by biological evolution
  - Reproduction, Mutation, Recombination, Selection
- EAs represent a set of search techniques used in computing to find the solutions to optimization problems



Evolutionary Algorithms (EAs)

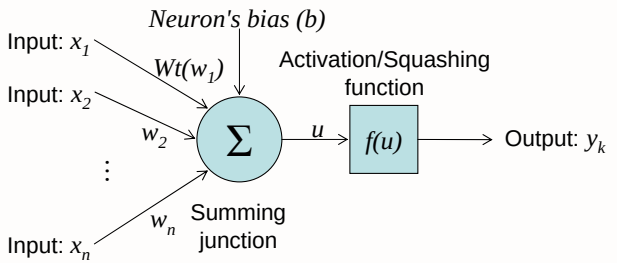
- EAs can be categorized into the following Classes
  - Genetic Algorithms (GAs)
  - Evolution strategies
  - Evolutionary programming
  - Genetic programming
  - Classifier systems
- Examples
  - Simulated annealing
    - Generic probabilistic meta-algorithm for the global optimization problem
  - Simulated hill-climbing
    - A mathematical optimization technique which belongs to the family of local search

Artificial Neural Networks (ANNs)

- A Neural Network is a network of biological neurons
- ANNs are non-linear statistical data modelling tools
- Used to acquire knowledge from the environment (known as self-learning property)
- The weights of the neurons are determined in a learning process
- They can be used to model complex relationships between inputs and outputs or to find patterns in data

Artificial Neural Networks (ANNs)

- A neuron *k* that connects *n* inputs can be described as:



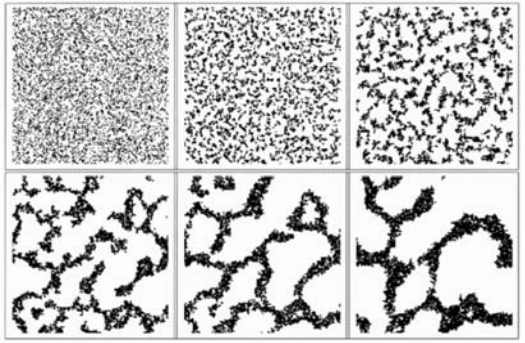
$$y_k = f(u_k) = f\left(\sum_{j=1}^{n} w_{kj} x_j + b_k\right)$$

Swarm Intelligence (SI)

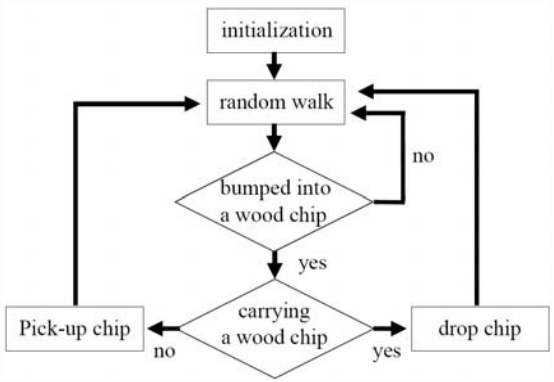
- An Artificial Intelligence (AI) technique based on the observations of the collective behavior in decentralized and self-organized systems
- Typically made up of a population of simple agents interacting locally with one another and with their environment (no centralized control)
- Local interactions between autonomously acting agents often lead to the emergence of global behavior
  - *Examples*: Ant/bee/termite colonies, bird flocking, animal herding, bacteria growth, and fish schooling

SI – Example of Ant Colonies

- Ants solve complex tasks by simple local means
- Ant productivity is better than the sum of their single activities
- Ants are "grand masters" in search and exploration



SI – Example of Ant Colonies



"The emergent collective intelligence of groups of simple agents." (Bonabeau)

SI Properties

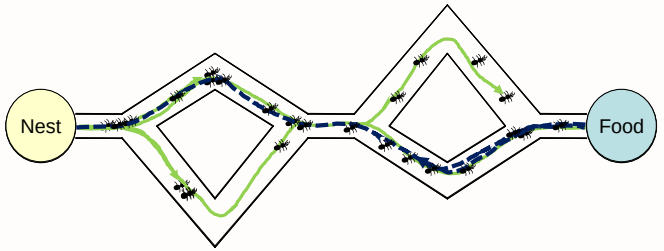
- Properties of Swarm Intelligence
  - Agents are assumed to be simple
  - Indirect agent communication
  - Global behavior may be emergent
    - Specific local programming not necessary
  - Behaviors are robust
    - Required in unpredictable environments
  - Individuals are not important

What is Stigmergy?

- Stigmergy is a mechanism of spontaneous, indirect coordination between agents or actions, where the trace left in the environment by an action stimulates the performance of a subsequent action, by the same or a different agent
  - Produces complex, apparently intelligent structures, without need for any planning, control, or even communication between the agents
  - supports efficient collaboration between extremely simple agents, who lack any memory, intelligence or even awareness of each other
- Stigmergy is a form of self-organization first observed in social insects

SI Example: Collective Foraging by Ants

- Starting from the nest, a random search for the food is performed by foraging ants
- Pheromone trails are used to identify the path for returning to the nest
- The significant pheromone concentration produced by returning ants marks the shorted path



Principles of Swarm Intelligence

- What makes a Swarm Intelligent system work?

• Positive Feedback	• Randomness
• Negative Feedback	• Multiple Interactions

- Positive Feedback reinforces good solutions
  - Ants are able to attract more help when a food source is found
  - More ants on a trail increases pheromone and attracts even more ants
- Negative Feedback removes bad or old solutions from the collective memory
  - Pheromone decay
  - Distant food sources are exploited last
    - Pheromone has less time to decay on closer solutions

Principles of Swarm Intelligence

- Randomness allows new solutions to arise and directs current ones
  - Ant decisions are random
    - Exploration probability
  - Food sources are found randomly
- Multiple Interactions: No individual can solve a given problem. Only through the interaction of many can a solution be found
  - One ant cannot forage for food; pheromone would decay too fast
  - Many ants are needed to sustain the pheromone trail
  - More food can be found faster

SI Routing Overview

- Ant-Based Control
  - Ant Based Control (ABC) is introduced to route calls on a circuit-switched telephone network. ABC is the first SI routing algorithm for telecommunications networks
- AntNet
  - AntNet is introduced to route information in a packet switched network
  - AntNet is related to the Ant Colony Optimization (ACO) algorithm for solving Traveling Salesman type problems
- AntHocNet
  - A MANET routing algorithm based on AntNet which follows a reactive routing approach
- Termite
  - Also a MANET routing algorithm

SI Application in MANET Routing

- Routing in MANETs is an extension of Ant Foraging!
  - Ants looking for food…
  - Packets looking for destinations…
- Can routing be solved with SI?
- Can routing be an emergent behavior from the interaction of packets?

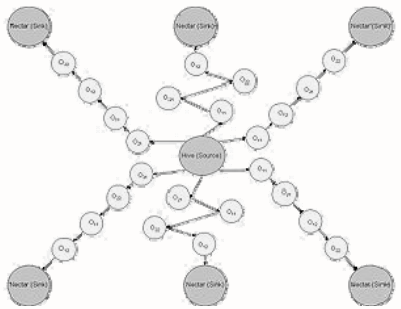
Ant-based Task Allocation

- Combined task allocation according to ACO paradigm has been investigated for MANETs
- The proposed architecture for MANETs is completely dependant on probabilistic decisions
- During the lifetime of the MANETs, nodes adapt the probability to execute one task out of a given set

Bee Colony Optimization (BCO)

- The BCO algorithm is inspired by the behavior of a honey bee colony in nectar collection
  - This biologically inspired approach is currently being employed to solve continuous optimization problems
    - training neural networks, job shop scheduling, server optimization

BCO provides a population-based search procedure in which individuals called foods positions are modified by the artificial bees with time and the bee's aim is to discover the places of food sources with high nectar amount and finally the one with the highest nectar



Bee Colony Optimization (BCO)

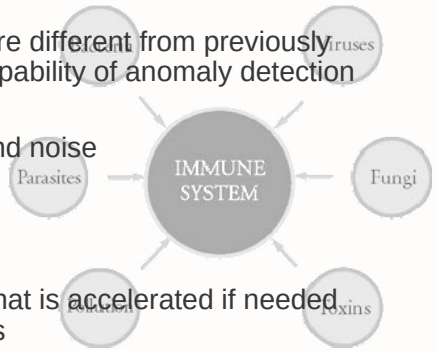
- Artificial bees fly around in a multidimensional search space and some (employed and onlooker bees) choose food sources depending on their experience of and their nest mates, and adjust their positions
- Some (scouts) fly and choose the food sources randomly without using experience
- If the nectar amount of a new source is higher than that of the previous one in their memory, they memorize the new position and forget the previous one
- Thus, ABC system combines local search methods, carried out by employed and onlooker bees, with global search methods, managed by onlookers and scouts, attempting to balance exploration and exploitation process

Artificial Immune System (AIS)

- Artificial immune systems are computational systems inspired by theoretical immunology and observed immune functions, principles and models, which are applied to complex problem domains
- The primary goal of an AIS is to efficiently detect changes in the environment from the normal system behavior in complex problem domains

Why the Immune System?

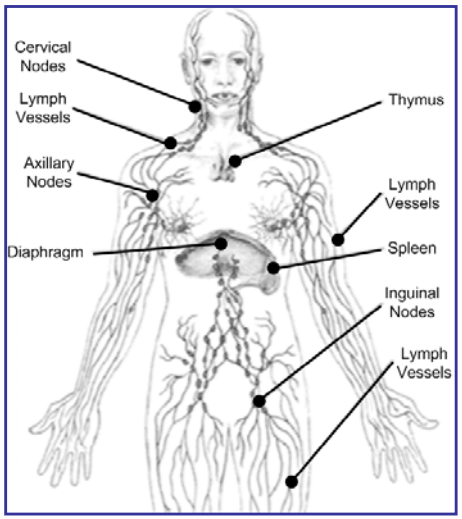
- Recognition
  - Ability to recognize pattern that are different from previously known or trained samples, i.e. capability of anomaly detection
- Robustness
  - Tolerance against interference and noise
- Diversity
  - Applicability in various domains
- Reinforcement learning
  - Inherent self-learning capability that is accelerated if needed through reinforcement techniques
- Memory
  - System-inherent memorization of trained pattern
- Distributed
  - Autonomous and distributed processing



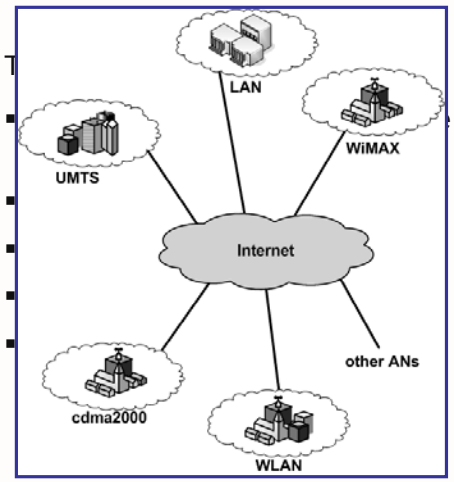
AIS – Application Examples

- Fault and anomaly detection
- Data mining (machine learning, pattern recognition)
- Agent based systems
- Autonomous control and robotics
- Scheduling and other optimization problems
- Security of information systems
- Misbehavior detection for MANETs based on the DSR protocol

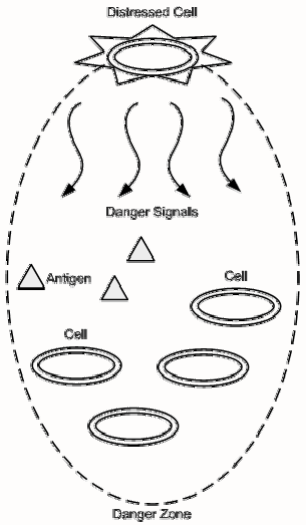
Human Immune System



Mapping HIS to NGMN

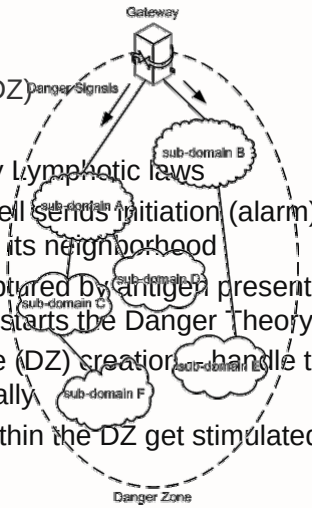


Danger Theory and NGMN



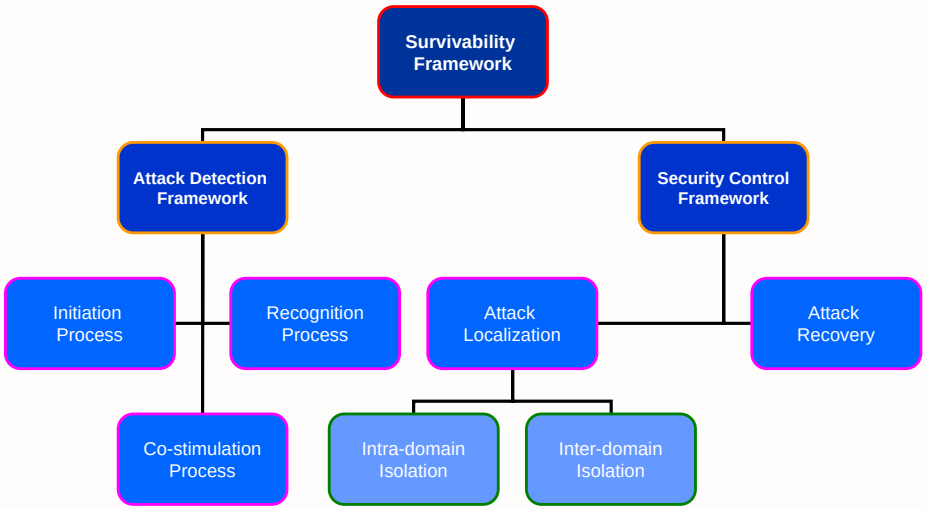
Mapping Danger Theory to NGMN

Danger Zone (DZ)



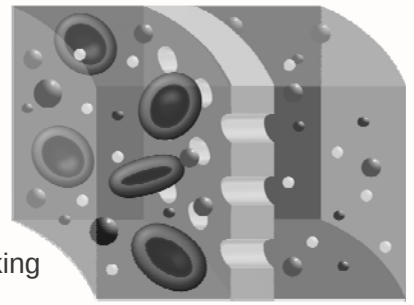
- Governed by Lymphatic laws
- Distressed cell sends initiation (alarm) signal (IS) to its neighborhood
- The IS is captured by antigen presenting cell (APC) – starts the Danger Theory
- Danger Zone (DZ) creation – handle the invaders locally
- Only cells within the DZ get stimulated

Survivability Framework in NGMN



Molecular and Cell Biology

- Properties
  - Basis of all biological systems
  - Specificity of information transfer
  - Similar structures in biology and in technology
    → Especially in computer networking

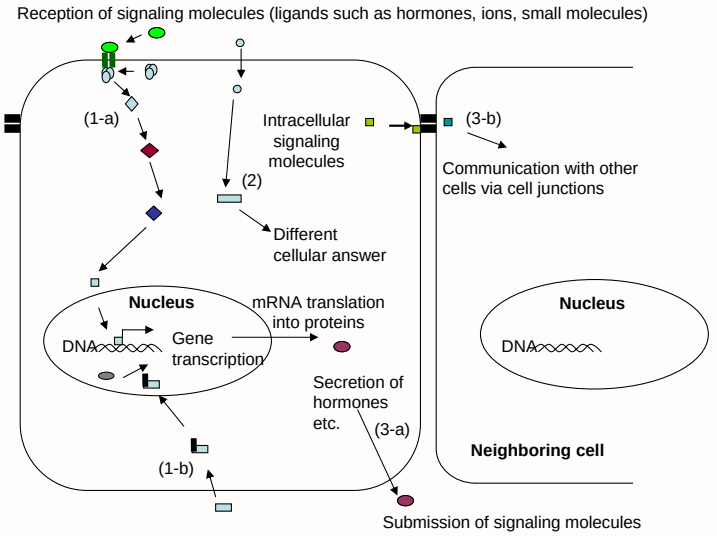


- Lessons to learn from biology
  - Efficient response to a request
  - Shortening of information pathways
  - Directing of messages to an applicable destination

Info Exchange in Cellular Environments

- Signaling in biological systems occurs at multiple levels and in many shapes
  - Signaling describes interactions between individual molecules
- Main cellular signaling techniques
  - Intracellular signaling
    - The information processing capabilities of a single cell
    - Received information particles initiate complex signaling cascades that finally lead to the cellular response
  - Intercellular signaling
    - Communication among multiple cells is performed by intercellular signaling pathways
    - Objective is to reach appropriate destinations and to induce a specific effect at this place

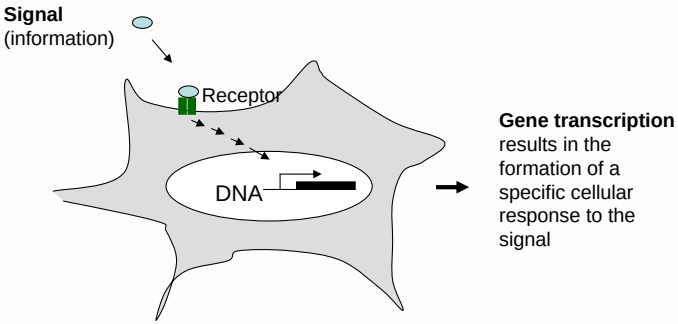
Intracellular Signaling Pathways



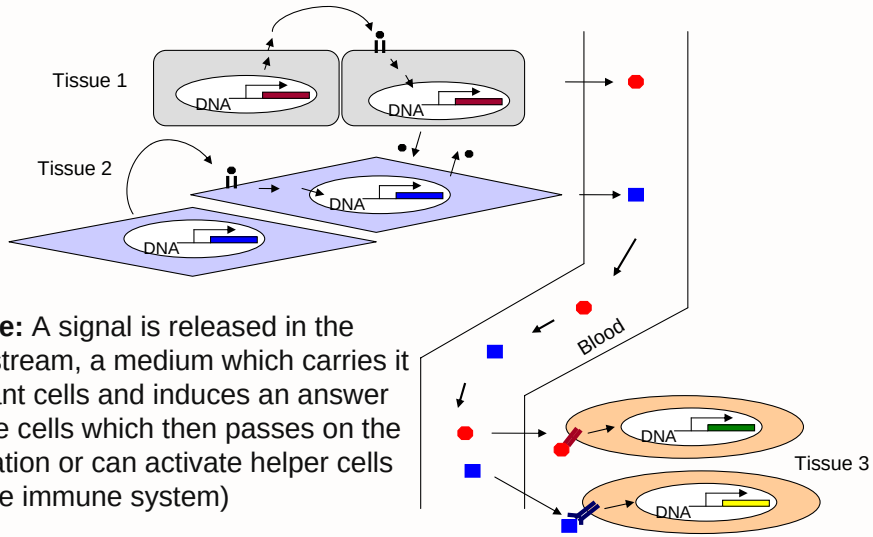
- Transfer via receptors on cell surface
- Reorganization of intracellular structure
- After processing the information, a specific cellular answer is initiated
- The effect could be the submission of a molecule

Intracellular Information Exchange

- **Local:** A signal reaches only cells in the neighborhood. The signal induces a signaling cascade in each target cell resulting in a very specific answer which vice versa affects neighboring cells



Intercellular Information Exchange



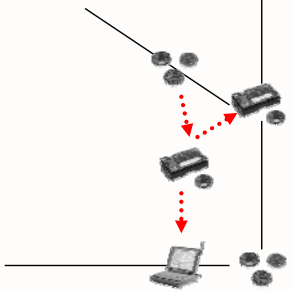
Remote: A signal is released in the blood stream, a medium which carries it to distant cells and induces an answer in these cells which then passes on the information or can activate helper cells (e.g. the immune system)

Lessons to be Learnt

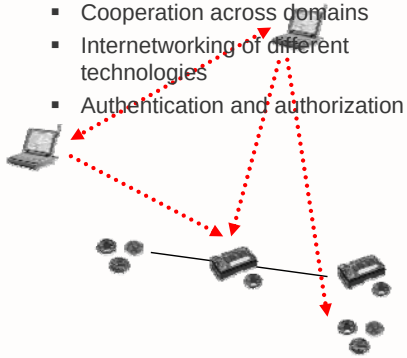
- The adaptation of mechanisms known from molecular and cell biology promises to enable more efficient information exchange
- New concepts for behavior patterns of network nodes
  - Improved efficiency and reliability of the entire communication system
  - Flexible self-organizing infrastructures
- Main concepts to be exploited in the context of communication networks
  - Signaling pathways based on specific signal cascades with stimulating and inhibitory functionality used for intracellular communication
  - Diffuse (probabilistic) communication with specific encoding of the destination receptors for intercellular communication

Adaptation to Networking

- Local mechanisms
  - Adaptive group formation
  - Optimized task allocation
  - Efficient group communication
  - Data aggregation and filtering
  - Reliability and redundancy



- Remote mechanisms
  - Localization of significant relays, helpers, or cooperation partners
  - Semantics of transmitted messages
  - Cooperation across domains
  - Internetworking of different technologies
  - Authentication and authorization



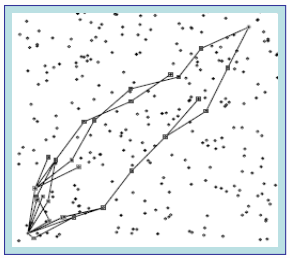
New elements incorporating the NGMN

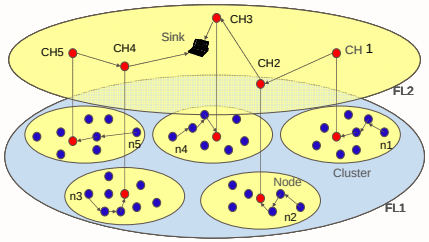
Some examples include:

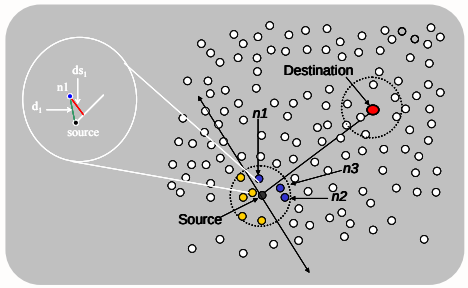
- Wireless sensor networks
  - Monitoring elements for NGMN efficient operation
- Mobile and vehicular ad hoc networks
  - Increasing the coverage and capacity of the NGMN
- Wireless mesh networks
  - Increasing reliability and providing an alternative backbone

Hierarchical Wireless Sensor Networks

- Sensor clustering for efficient routing
- Layered topology design for better data aggregation
- Secure sensor networking

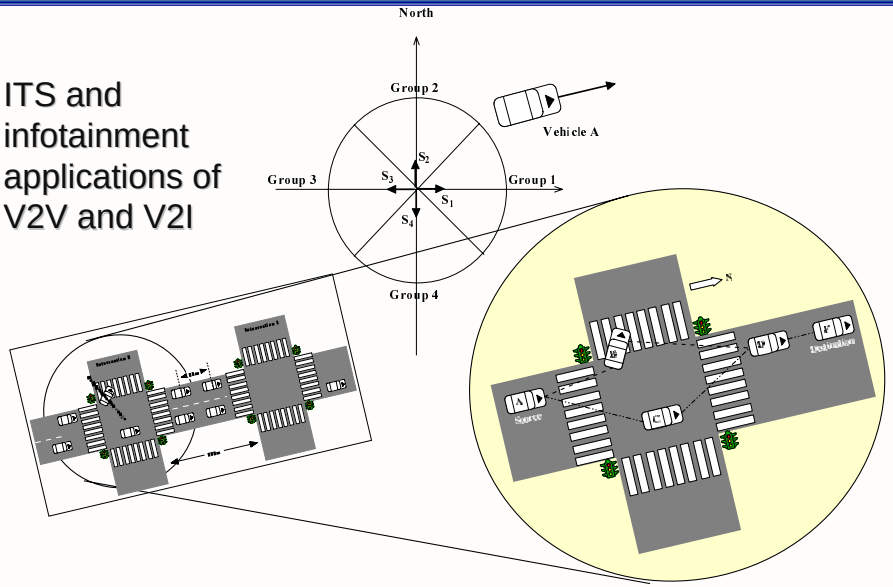






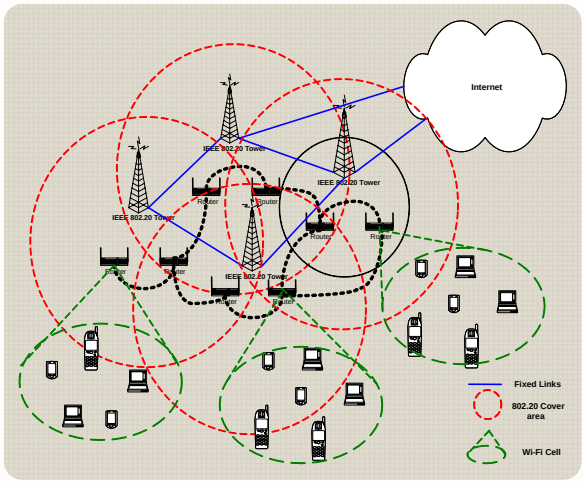
Vehicular Ad Hoc Networks

ITS and infotainment applications of V2V and V2I



Multi-layered Wireless Mesh Networks

- Developing a new backbone network for the Internet
- Applications:
  - Emergency
  - Fault tolerance
  - Increased throughput
  - Reliability



Closing Remarks

Mobile Networks & Topologies

Networks

- Advanced cellular networks
  - GSM, GPRS, UMTS, cdmaOne, cdma2000, HSDPA, LTE, …
- Wireless LAN IEEE 802.11 family
- Wireless MAN IEEE 802.16 family
- Other emerging technologies

Topologies

- Cellular based systems (centralized)
- Ad hoc networks fixed vehicular nodes (decentralized)
- Mesh networks (mixing centralized and decentralized)

NGMN Developments

- Development trend of NGMN and Wireless IP has been separated into two distinct ways:
  - Cellular based – moving from CS to PS and all IP-based
  - IP-oriented standards oriented around IEEE 802.1x and 802.2x
- No matter how these rather exclusive directions develop, the future of mobile data will hang around a heterogeneous solution that will include both approaches
- Providing QoS and security in NGMN and Wireless IP will be the task of all layers of the network protocol stack, with particular attention at the higher layers in order to be aligned with the heterogeneous nature of the future networks
- Bandwidth and resource management of large number of network users will eventually push W-LAN and W-MAN standards into licensed spectrum

Bio-Inspiration Role

- Very little number of studies on biologically inspired network models exist in the literature
  - Available models mainly imitate some biological coordination aspects
- As for the nature, however, they could have great potential to assist with better and more efficient network management in mobile communications networks, particularly for the future dynamic non-centralized heterogeneous NGMN environment
  - To provide scalability, self-organization, self adaptation, sustainability, and added network security

Mobile Communications Networks

Evolving through biologically-inspired technologies

Thank You

AJ

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