Mobile self-organizing networks

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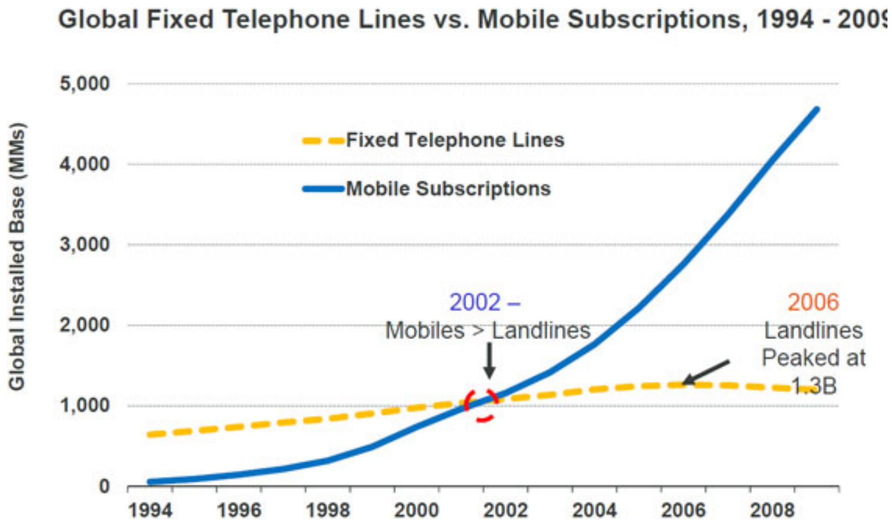
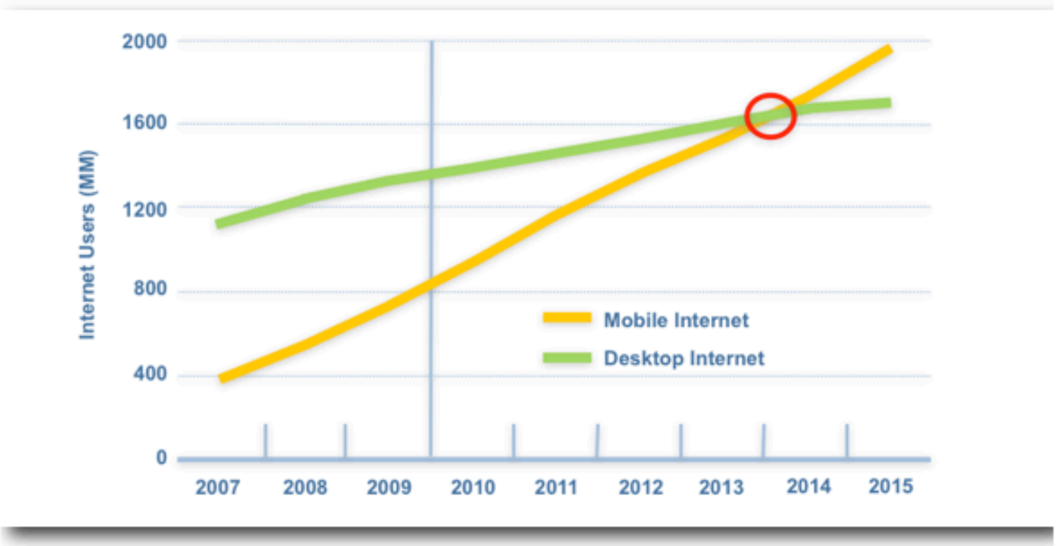
Trends: Mobile user numbers

Source: http://mybroadband.co.za/news/wp-content/uploads/2012/12/Global-Fixed-Telephone-Lines-vs.-Mobile-Subscriptions-1994-2009.jpg





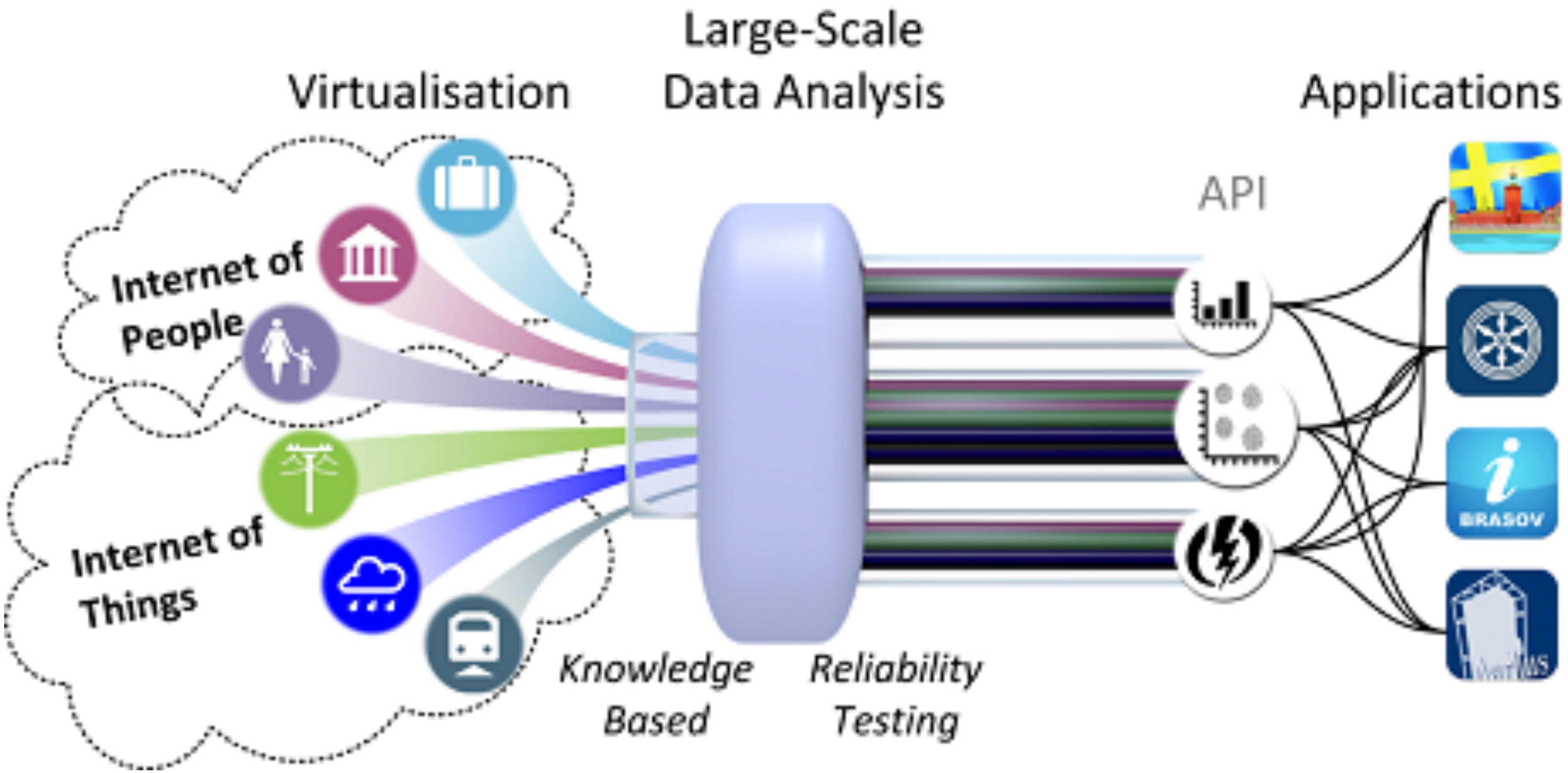
Source: https://jmerril.files.wordpress.com/2011/11/screen-shot-2011-11-16-at-9-39-15-pm1.png

Trends: Internet of Things

Smart Cities - M2M applications everywhere

Source: Eurotech - Smart City – Many Applications and Devices

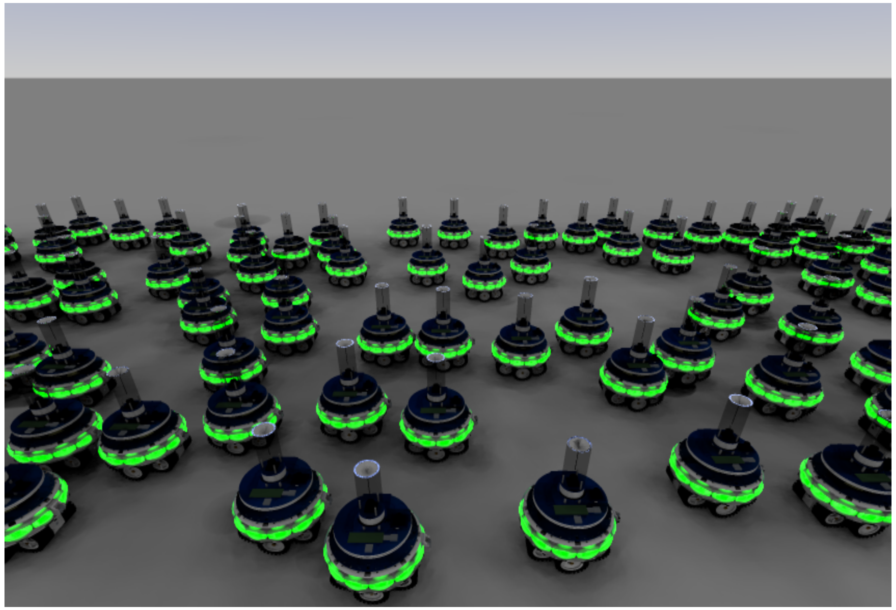
Trends: Crowd sensing

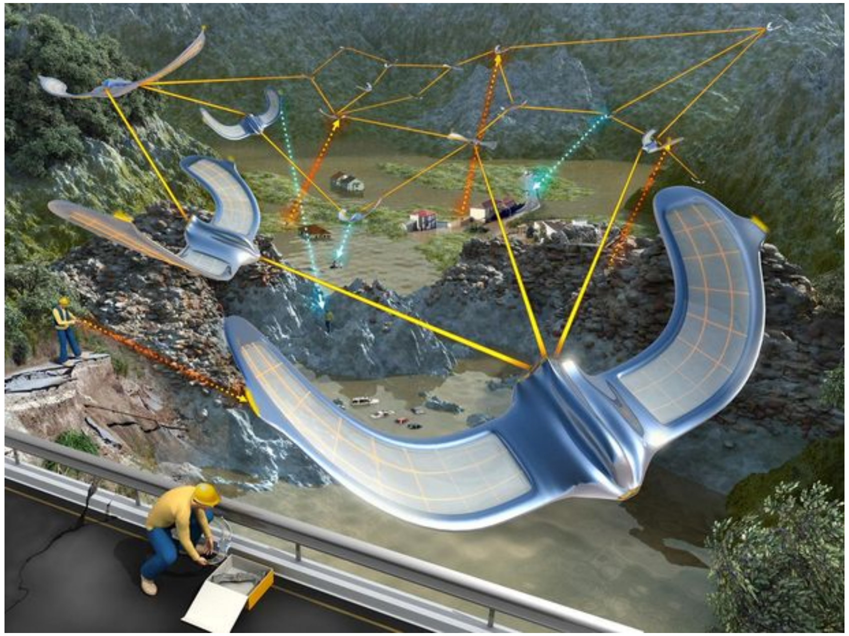


Source: http://www.ict-citypulse.eu/page/sites/default/files/traysequence-460_0.png

Trends: self-organized flocking

- Mobiles users moving in autonomous groups: flocks
  - UAVs, robots, cars
- Novel research: split and join actions

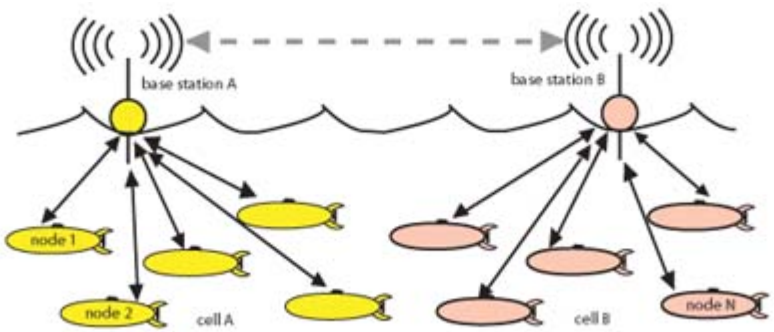




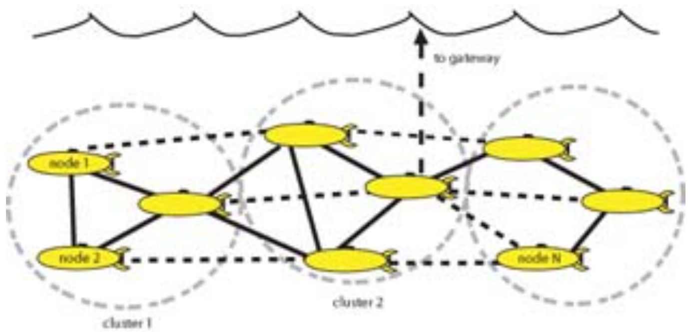
Network topologies

- Types of network topologies
  - Centralized
  - Decentralized (peer-to-peer)
  - Hybrid

Centralized



Decentralized



Centralized topology

- Communication from one node to another goes through a hub or base station (BS)
- Hub station controls nodes and monitors transmissions from each node
- Hub manages access by nodes to network's allocated bandwidth
- Configuration for cellular mobile and WLAN networks

Advantages of centralized topology

- Efficient use of transmit power
- Optimized placement of Hub/BS: minimizing obstruction
- Hub/BS: provides connection to backbone network
- Power control
  - a central point can determine required power for nodes to minimize interference and conserve battery

Disadvantages of centralized topology

- Single point of failure
- Can not deal with unpredictable propagation environments
- Cannot cover wide areas
  - where connections exceed range of single link
- **Not suitable for self-organizing networks**
- Requires significant infrastructure setup

Decentralized topologies

- Fully-connected network
  - All nodes can communicate directly
  - Requires nodes to be co-located

- Multi-hop network
  - If nodes can not directly reach the destination: intermediate nodes must relay messages to destination
  - Widely used in ad-hoc and mesh networks
    - Not possible to guarantee connectivity of all nodes

Fully-connected peer-to-peer network

- Advantages
  - No single point of failure
  - No store-and-forward delay
  - A node can be designated as a gateway to backbone network
- Disadvantages
  - Performance degradation in large networks
  - Near-far problem

Multi-hop peer-to-peer

- Advantages
  - Only solution if no infrastructure available
  - Widely used in military applications
  - Gaining popularity in other types of wireless networks
    - Ad hoc networks
    - Sensor networks

- Disadvantages
  - Multiple store-and-forwards
  - Increase delay
    - for users separated by multiple hops
  - No central timing or power control authority

Types of networks

- WiFi/ 802.11
  - Two modes
    - Centralized: wireless local area data network
    - Peer-to-peer: MAC/PHY for ad hoc networks

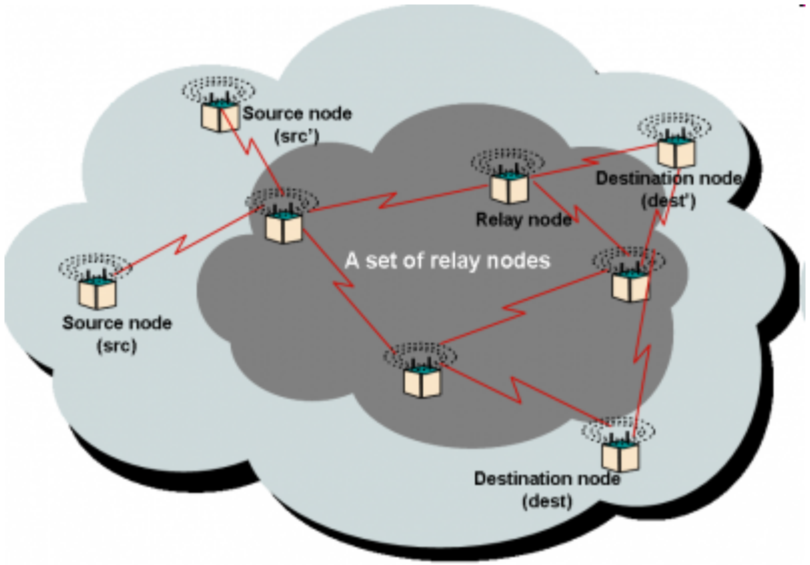
- Self-organized networks
  - Multi-hop peer-to-peer networks
  - Hybrid networks
  - Unicast, multicast and broadcast networks

- Wireless sensor networks

Self-organizing networks

- Dynamic topology
  - nodes enter and leave the network continuously
- No centralized control or fixed infrastructure

- Application areas:
  - Meetings
  - Emergency or disaster relief
  - Military communications
  - Wearable computers
  - Sensor networks



Self-organizing networks

- Limited communication range of the mobile nodes
  - Enables spatial reuse of limited bandwidth: increased network capacity
- Each mobil node is a
  - Packet source
  - Packet sink
  - Router
- Problem: how to determine where a destination node is located relative to a sending node

„Routing” in self-organizing networks

- Route-finding is a current area of much research
  - Want to determine an “optimal”way to find “optimal”routes
- Dynamic links
  - Broken links must be updated
  - New links must be formed
  - Based on this new information: routes must be modified
- Frequency of route changes a function of node mobility

Issues in self-organizing networks

- Routing performance
  - Routes change over time
    - due to node mobility
  - To avoid long delays when sending packets
  - But also to avoid lots of route maintenance overhead

- MAC
  - Broadcast communication channel
  - Neighbor nodes change over time
  - Sleep mode: to reduce energy drain
  - No coordination/cooperation among nodes?

Issues in self-organizing networks

- Quality of service
  - Link variability
  - Collisions
  - Congestion
- Security
  - New vulnerabilities and complexities
  - Routing denial of service
    - Nodes may agree to route packets
    - Nodes may then fail to do so
    - Broken, malicious, selfish nodes
  - Key distribution and trust issues

MAC protocols

- No centralized control therefore:
  - Nodes independently determine access
  - Local nodes elected to control channel access

- Goals for MAC protocols
  - High channel efficiency
  - Low power
  - Scalable
  - Support for prioritization (QoS)
  - Distributed operation
  - Low control overhead

MAC: Channel separation

- Common channel vs. multiple channels

- Typical use of channel
  - Data transmission
  - RTS/CTS handshake
  - Carrier sensing

- **Common**: single channel for all packets
- **Multiple**: some packets (overhead) on one channel, while other packets (data) on others
  - allow more simultaneous users

Single channel

- Data and control messages on the same channel
- Collisions and contention
  - Handshake protocol
  - ACKs
  - Backoff protocol

Multiple channels

- Typically, one channel for control, others for data

- **TDMA-based**
  - Time slots + synchronization
  - Best with real-time, periodic data

- **FDMA-based**
  - Allows multiple nodes to transmit simultaneously

Multiple channels (cont.)

- **CDMA-based**
  - Simultaneous transmissions via code separation
- **SDMA-based separation**
  - Directional antennas to transmit in particular direction
- **Hybrid schemes**
  - Combine channel separation methods

Topologies: Flat

- **Flat**
  - Nodes make independent decisions to access the channel
    - Local coordination via handshaking, carrier sensing
  - **Single-hop**: concerned only with immediate neighbors
    Scalability issues
  - **Multi-hop**: some notion of nodes outside local neighborhood
    - Most use multiple channels

Topologies: Clustered

- **Clustered**
  - Elect local cluster head (CH) to perform control/management of network resources
  - Reduces burden on nodes, increases burden on cluster head
    - Good for heterogeneous networks
    - VBA: elect CH based on lowest IP address
    - WCA: elect CH based on weighting of distance to nbrs, battery power, mobility and connectivity; allows roaming between clusters
    - Jin, GPC: elect CH based on battery power
    - Bluetooth: elect CH (Master) as node that initiated cluster (piconet)

Reducing energy consumption

- Radio operates in 3 modes: transmit, receive, standby
- Reduce transmit power
  - Use "just enough" to reach intended destination
- Place nodes in standby mode as much as possible
  - Nodes do not need to be on when not receiving data
  - Requires nodes to know when they must listen to the channel and when they can "sleep"
  - MAC protocols cannot use "promiscuous" mode to listen to other conversations
  - Node must know when other nodes have data to transmit to it

Reducing energy consumption (cont.)

- Collisions should be minimized
  - Retransmissions expend energy
  - Introduce delays (e.g. Random Assessment Delay)
  - Reduce number of ACKs required
  - Use contention for reservations and contention-free for data transmission
- Allocate contiguous slots for transmission/reception
  - Avoids power/time in switching from Tx to Rx
- Have node buffer packets and transmit all packets at once
  - Allows node to remain asleep for long time
  - Trade-off in delay to receive packets and buffer size

Reducing energy consumption (cont.)

- Make protocol decisions based on battery level
  - Choose cluster head to have plenty of energy
  - Give nodes with low energy priority in contention
- Reduce control overhead
  - Need control to avoid collisions, but reduce as much as possible

Transmission Initiation

- **Sender-initiated**
  - In most of the protocols
  - Sender attempts to access channel when it has data
- **Receiver-initiated**
  - Receiver attempts to clear channel for transmissions
  - Send request-to-transmit (RTR) to all neighbors or specific node
  - Only efficient if large amount of traffic on network

MŰEGYETEM 1782

Information dissemination in mobile self-organized networks

Special case: multihop broadcast

- Multihop broadcast algorithms
  - global (multihop) broadcast service for the dissemination of some control information
- The naive first implementation: flooding
  - every node repeats the message after it is first received
- The central problem of broadcast algorithms is to decide
  - when
  - who should retransmit messages
- Too many retransmissions
  - cause collisions
  - waste the network bandwidth
- Choosing the smallest forwarding set is not easy
  - a global view of the network is not available
  - local information gets obsolete very quickly if the velocity of the nodes is high

Uses cases

- Wireless sensor networks
  - Gathering measurements
  - Sending queries
- Robotic swarms
  - Keeping the swarm together
  - Distributing information
- Vehicular networks
  - Traffic info
  - Efficient route planning
  - Alerts

Information dissemination

- The goal: disseminate a message to (almost) all nodes in the network minimizing resource usage.
- Blind flood
  - Broadcast storm
- Randomized
  - Gossiping
- Quasi local information
  - SBA, MMSBA, MIOBIO

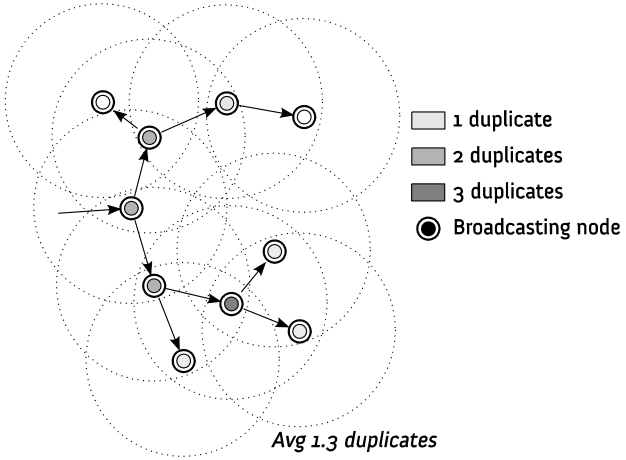
Self-pruning algorithms

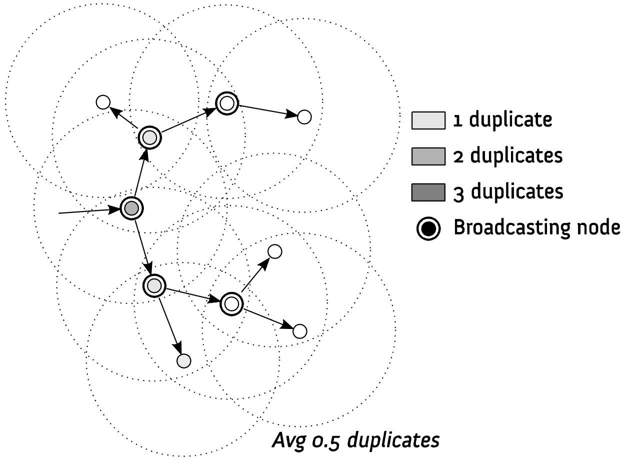
Scalable Broadcast Algorithm (SBA)

- When a node receives a broadcasted packet from a node: excludes the neighbours of this node from the set of his own neighbours
- The resulting set is the set of the potentially interested nodes
- Random Assessment Delay (RAD) mechanism

SBA

(a) Neighbor node starts broadcasting (b) SBA updates the set of interested nodes



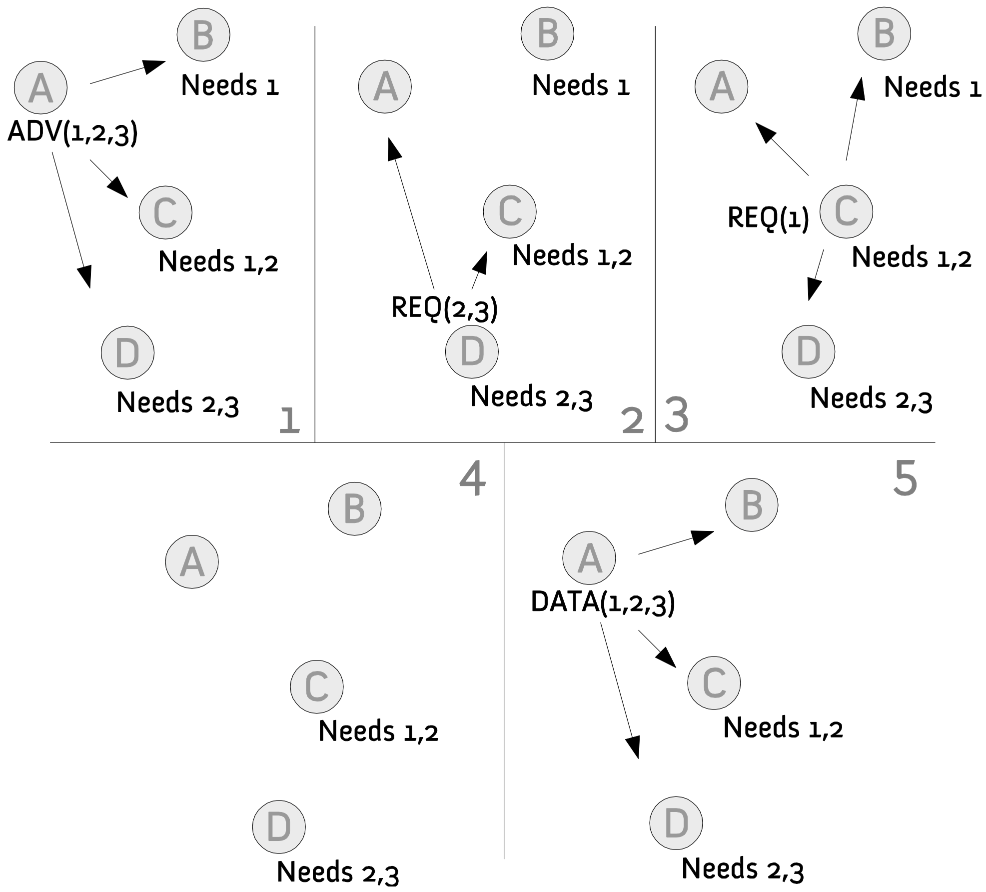


MIOBIO

- Uses a simple 3-stage handshake to discover neighbors that are interested in one of the carried messages
- Reduce unnecessary load of neighbouring nodes ("spamming")
- Three different types of messages:

  - *ADV*: the list of messages that the sending node has *REQ*: by sending it the neighbor nodes indicate their interest in the advertised messages
  - *DATA*: the data message, which contains the requested information

MIOBIO



A
B
C
D
ADV(1,2,3)
Needs 1
Needs 1,2
Needs 2,3
1
REQ(2,3)
2
REQ(1)
3
4
DATA(1,2,3)
5

Which algorithm to use?

- Plenty of multihop broadcast algorithms, working well in different environments
- The environment is changing so rapidly: there is no hope for choosing a theoretically optimal algorithm
- One solution: adaptive approach, the system “self-tunes” itself
- Our approach: a biologically inspired method, natural selection

Natural selection

- Main principle: to have many algorithm individuals that compete with each other in the system
- The individuals with the highest fitness will reproduce faster than the less fit ones
- Fitness estimation: direct feedback is not feasible
- Instead of trying to collect performance measurements at the sender
    - the sender attaches the code of the sender algorithm to every packet
    - delegates the decision to the receiver
  - Local fitness function at every node

Local fitness evaluation

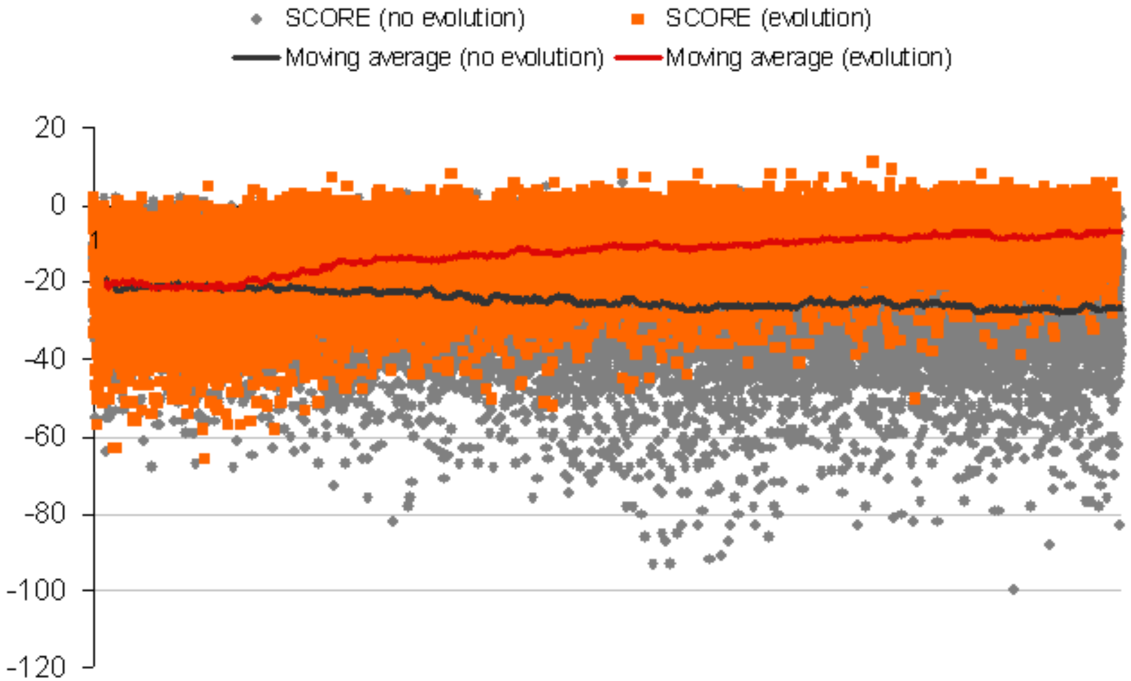
- Every message carrying payload will also carry a genetic code of the sending algorithm
- The receiver knows which algorithms perform best: the highest number of useful messages
- When the algorithm individual dies at the receiver node: it will choose the best algorithm based on his local measurements
- Reduces overhead compared with a conventional statistics collecting scenario

Evolutional concept

- If using genetical programming, the basic elements of the algorithms can recombine: new algorithms are born
- The competing set is changing rapidly
- Self-organization without any control!

Evolution results

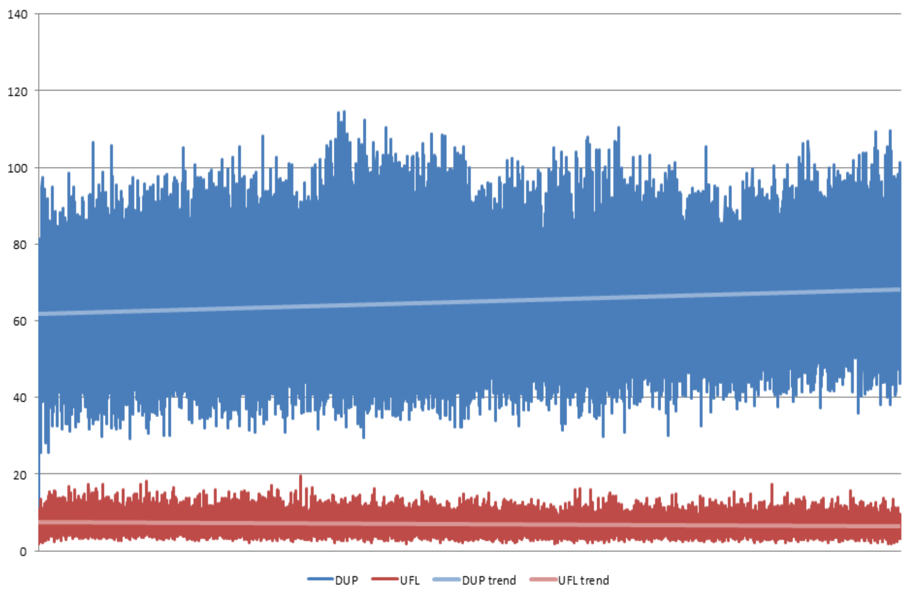
- Difference between useful and duplicated messages
  - Blue: without evolution
  - Red: with evolution



Robustness

- Ratio of malware code to other 3 algorithms : 5, 30, 70%
- 70% case:

Without evolution:



With evolution: