



Mobile Agents for Adaptive Reconfigurable Wireless Networks

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Outline of Presentation

- Introduction
- Overview of short-range wireless communications
- Mobile agents and mobile codes
- Bluescouts: A Bluetooth scatternet formation protocol based on mobile agents
- WISEMAN: A mobile code platform for wireless sensor networks
- Research directions on mobile agents in wireless networks

The University of British Columbia



The University of British Columbia

- 102 years old
- A world class university with a spectacular location
- Consistently ranked among world's top 50 universities
- #36, Shanghai Jiaotong University World University Ranking 2009
- Annual budget of \$1,600,000,000
- More than 50,000 students
- 12 faculties and 11 schools, 2 campuses in Vancouver and Kelowna
- World class faculties in medicine, life sciences, law, engineering and management
- One home-grown and one resident Nobel Laureates
 - Michael Smith, Nobel Prize in chemistry, 1993
 - Carl Wieman, Nobel Prize in physics, 2001

Department of Electrical & Computer Engineering

- 56 faculty members, 11 IEEE Fellows
- Two graduate degrees: BAsC EE, BAsC CE
- Three postgraduate degrees: PhD, MASc, MEng
- Approximately 800 undergraduate students (year 2, 3, 4) and 350 graduate students
- **Research groups:**
 - Biotechnology Group
 - Communications Group
 - Control and Robotics Group
 - Computer and Software Engineering Group
 - Electric Power and Energy Systems Group
 - Microsystems and Nanotechnology Group
 - Signal Processing and Multimedia Group
 - Very Large Scale Integration Group

Communications Group @ ECE, UBC

- **Vijay Bhargava** – error correcting codes, wireless systems and technologies beyond 3G, cognitive radio
- **Lutz Lampe** – modulation and coding, MIMO systems, CDMA, ultra-wideband (UWB), wireless sensor networks
- **Cyril Leung** – wireless communications, error control coding, modulation techniques, multiple access, security
- **Victor Leung** – network protocols and management techniques, wireless networks and mobile systems, vehicular telematics
- **Dave Michelson** - propagation and channel modeling for wireless communications system design, low-profile antennas
- **Robert Schober** – detection, space-time coding, cooperative diversity, CDMA, equalization
- **Vincent Wong** – wireless networks, ad hoc, sensor networks

strong research focus on wireless

My Research Focus

- Network architectures, protocols, management algorithms, modeling and performance evaluations
- Two main thrusts:
 - Wireless telecom 3G and beyond
 - Radio resource management for high speed packet access
 - Interworking of heterogeneous wireless networks
 - Handoff and mobility management
 - Quality of service provisioning
 - Authentication, authorization and accounting
 - Networking for license-free wireless communications
 - Wireless personal area networks
 - Wireless sensor networks
 - Vehicular ad hoc networks and vehicle-infrastructure integration
 - Wireless body area networks
 - RFID networks

My Team

- **Postdoctoral fellows** – Dr. Alireza Attar, Dr. Sergio Gonzalez, Dr. Hongbo Guo, Dr. Sang-Wook Han, Dr. Xuedong Liang.
- **PhD students** – Amr Al Asaad, Mohsen Amiri, Hui Chen, Ashfiqua Connie, Javad Hajipour, SeyedAli HosseiniNezhad, , Pouya Kamalinejad, Haoming Li, Mahmood Minhas, Rukhsana Ruby, Bambang Sarif, Jun-Bae Seo, Kaveh Shafiee, Peyman TalebiFard, Narjes Torabi, Jun Wang, Jie Zhang
- **MASc students** – MadhuSudhanan J Sharma, Wei Bao, Xiaolei Hao.
- **Collaborators** – Prof. Henry Chan (Polytechnic U. of HK), Prof. Min Chen (SNU Korea), Prof. Jiannong Cao (Polytechnic U. of HK), Prof. Sathish Gopalakrishnan, Dr. Song Guo (Aizu U. Japan), Prof. Hong Ji (BUPT, China), Dr. Zhifeng Jiang (China Netcom), Prof. Vikram Krishnamurthy, Dr. Ki-Dong Lee (LG), Prof. Panos Nasiopoulos, Dr. Qixiang Pang (General Dynamics), Dr. Helen Tang (DRDC), Prof. Son Vuong (UBC CS), Mr. Terrence Wong (Huawei Canada), Prof. Vincent Wong, Prof. Oliver Yang (U. Ottawa), Prof. Fei Yu (Carleton U.), Dr. Yan Zhang (Simula), Prof. Qian Zhang (HKUST), Prof. Yihua Zhu (Zhijiang U.Technology)

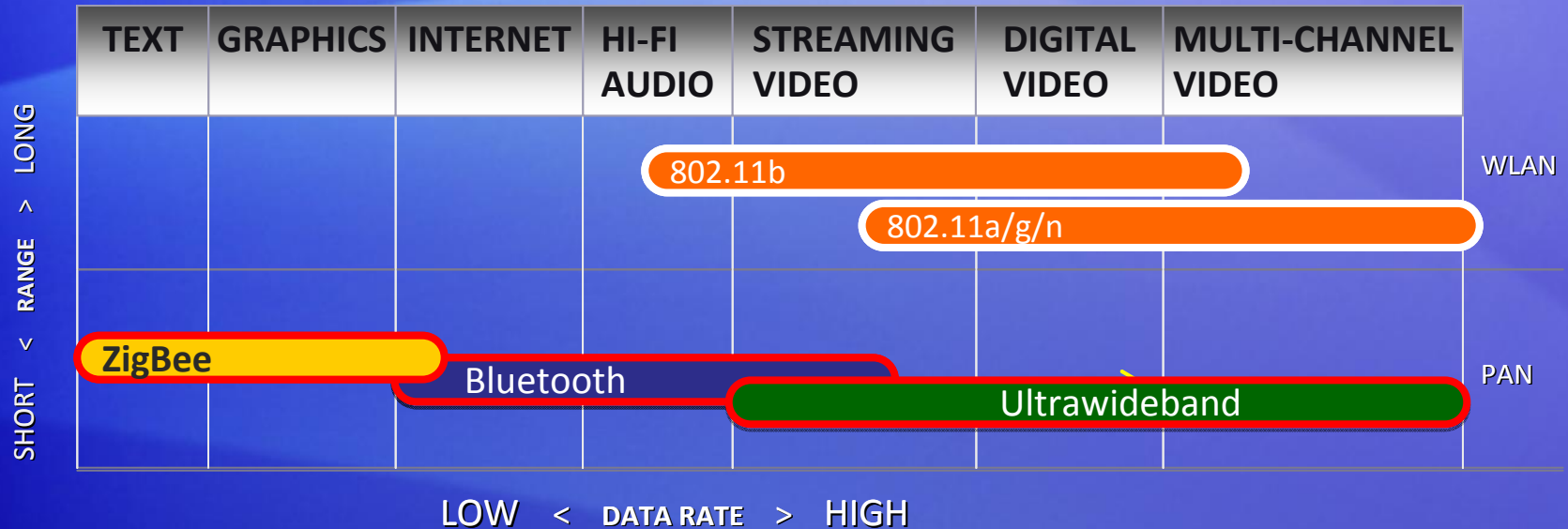
Overview of Short-Range Wireless Communications

WPAN and WSN

Overview of Short-Range Wireless Communications

- WLANs have become a pervasive means for portable PCs to connect to the Internet and for other networking applications, but...
- 802.11x radio incurs relatively high power consumption that is detrimental for portable devices.
- Other technologies exist: Bluetooth Low Energy, Zigbee, etc.
- Wide applicability range: home, industrial, medical, environmental, vehicular, etc.
- Enabler for Internet of Things, Cyber-physical Systems

Overview of Short-Range Wireless Communications



Ref: IEEE 802.15-03/305r0

Bluetooth and ZigBee cater to applications in which low data rates are sufficient.

Unlike 802.11x technology, Bluetooth and ZigBee were designed with significantly tighter considerations for reduced power consumption.

Ultra-wideband is also an emerging technology that supports high data rates, and low power consumption.

Overview of Short-Range Wireless Communications



Bluetooth

Introduced in the early 2000's; geared towards seamless interconnection of mostly compact, portable electronic devices to create Wireless Personal Area Networks (WPAN).

Promoted by a multi-company consortium.

- Reduced power consumption when compared to 802.11x.
- Bluetooth Low Energy technology for very long battery life.
- A key aspect of Bluetooth is the use of application profiles for audio, imaging, file transfer, networking, etc.

Overview of Short-Range Wireless Communications



ZigBee

Introduced in 2003, ZigBee devices are targeted at creating Wireless Sensor Networks (WSN) that require low-power and low data rate.

Also backed by a multi-company consortium.

- Intended for home and building automation, healthcare monitoring, and other consumer electronics.
- Incorporates IEEE 802.15.4 at PHY and MAC layers – up to 250 Kbps
- Promotes ultra-low power consumption that extends battery life (from a few months to a few years, depending on the application).

Overview of Short-Range Wireless Communications

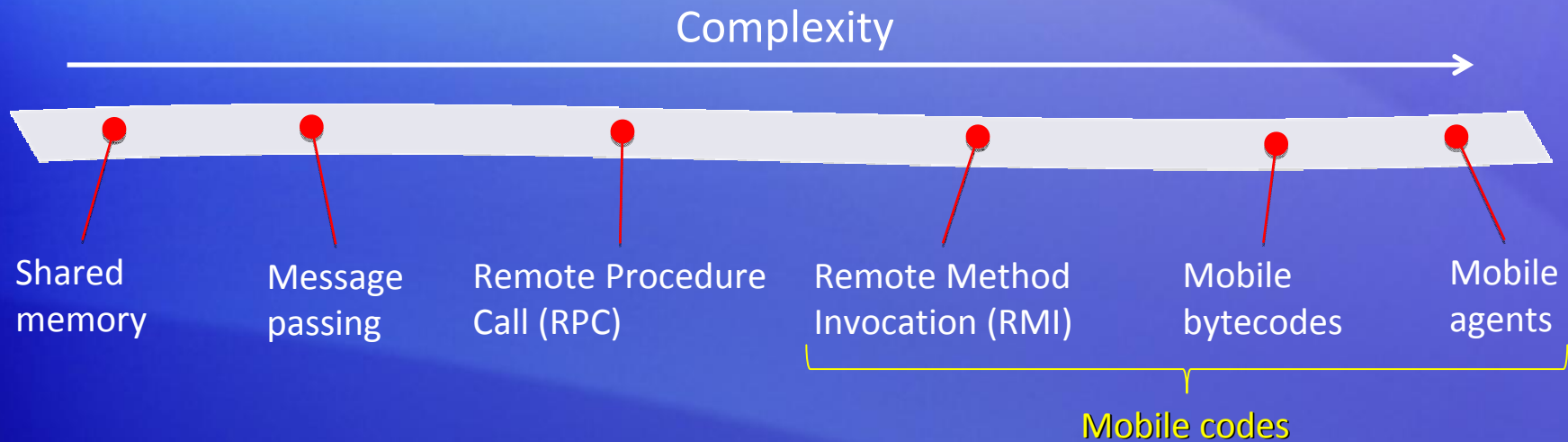
- Bluetooth and ZigBee-enabled devices now widely available for a range of consumer and industrial applications.
- Outstanding issues actively investigated by researchers in the area:
 - Network topology formation
 - Routing
 - Data transport
 - Device coordination
 - Service discovery
- We are interested in applying a novel methodology that promotes adaptability and easy reconfiguration of the algorithms implemented to tackle these problems.

Mobile Agents and Mobile Codes

Principles of Active Networking

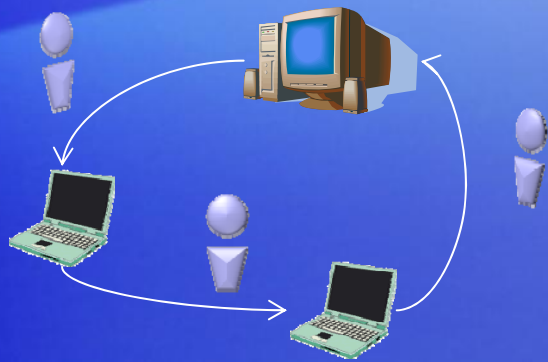
Mobile Agents and Mobile Codes

Data communications models for distributed systems



- Shared memory (local) and message passing (remote) are the simplest.
- RPC is slightly more complex; and with tighter synchronization constraints.
- Mobile codes: RMI, binary, agents; each with its own characteristics.

Mobile Agents and Mobile Codes



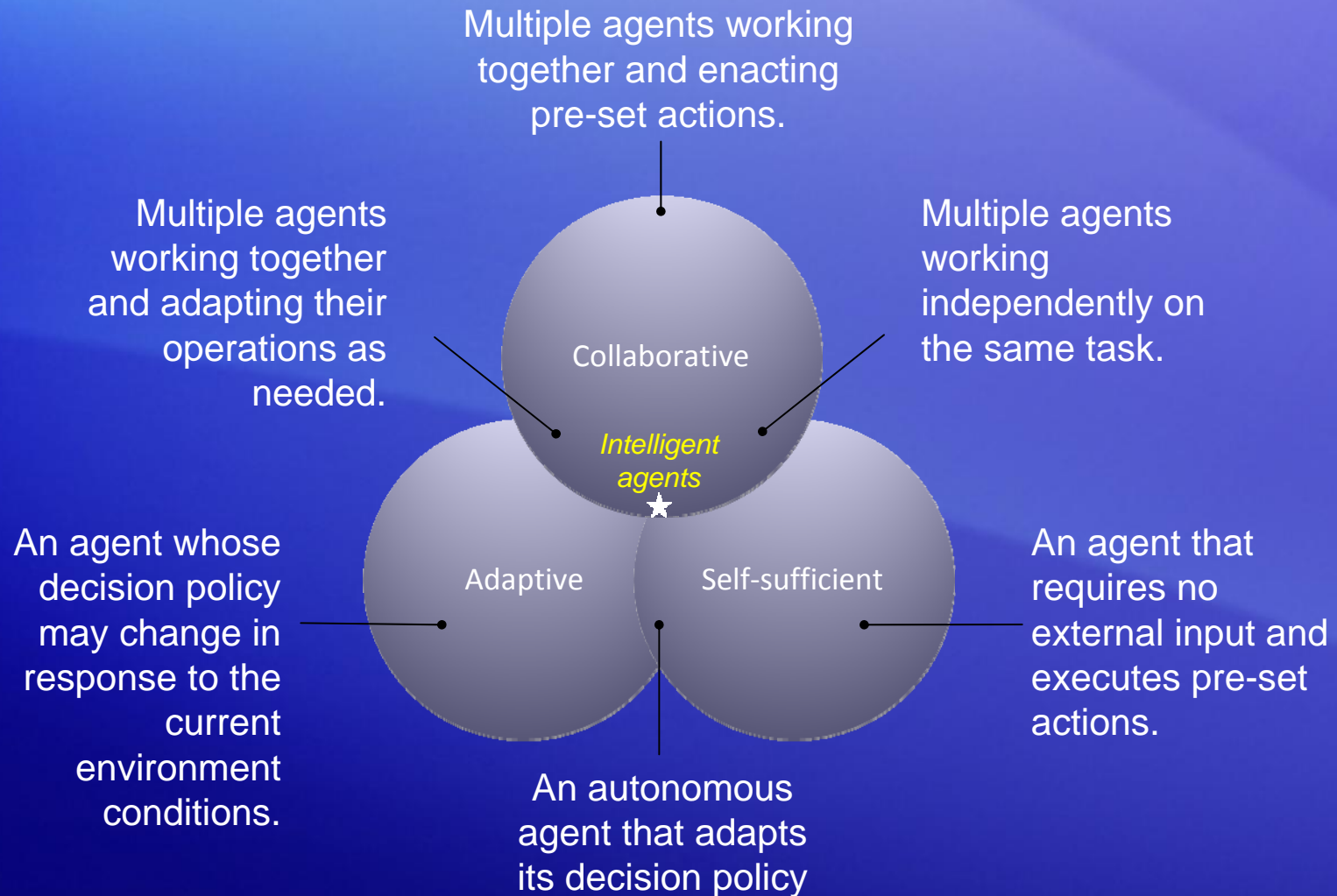
Mobile agents: Software entities that can relocate from one computer to another to accomplish a given task.

Their applicability was extensively studied throughout the 90s.

-
- A software agent reacts to its environment as determined by a policy implemented by the programmer. Mobility is an attribute.
 - Mobile agents require a code interpreter or execution environment.
 - Other possible characteristics: autonomous, intelligent, persistent, compact.
 - Applicability: E-commerce, personal assistance, brokering, information retrieval, network management, distributed monitoring, etc.

Mobile Agents and Mobile Codes

Classification of mobile agents



Mobile Agents and Mobile Codes

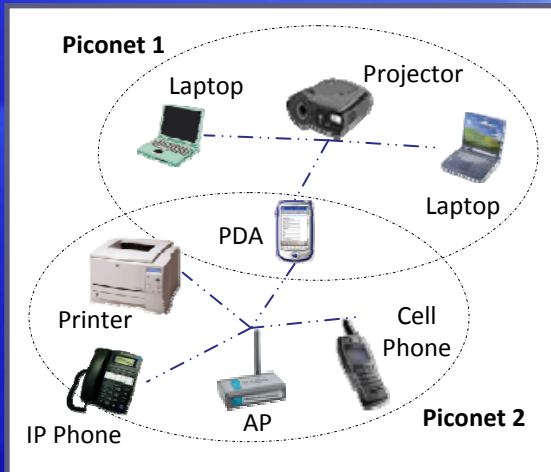
Employing Mobile Agents in Networking Applications

- There are no Mobile Agent applications.
- Instead, there are applications that can benefit from using Mobile Agents.
- Mobile Agents employed for automated network management = active networking.
- Initially, limited motivation for use in wireless networks
- Renewed interest for use in bandwidth-constrained wireless and personal area networks – Bluetooth Scatternets and Wireless Sensor Networks.

Bluescouts: A Scatternet Formation Protocol Based on Mobile Agents

Active networking in wireless networks

Scatternet Formation Based on Mobile Agents



Bluetooth devices (BDs) discover neighbouring devices assume either a master or slave role.

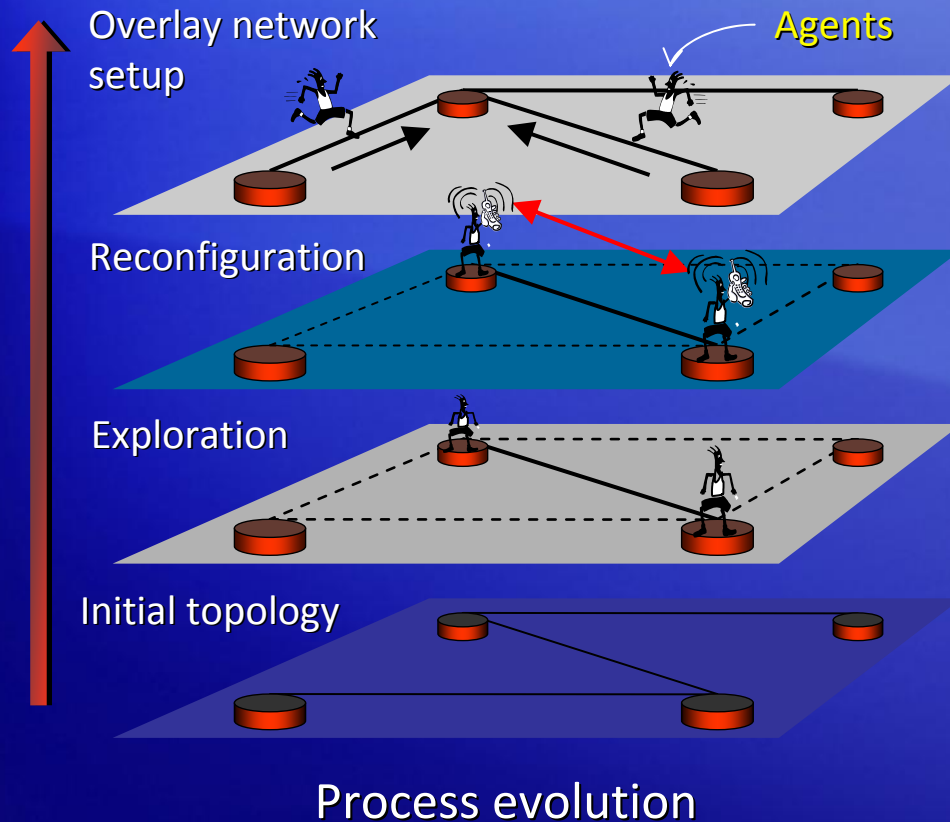
A master handles up to seven slaves in active communications connected in a star-shaped topology – *piconet*.

A collection of interconnected piconets becomes a *scatternet*.

- Problem definition: How do we create scatternets efficiently?
- Many existing proposals: Bluestar, Bluemesh, Bluenet, Bluetrees, TSFP, DTC, etc.
- Assumptions often made by existing scatternet formation methods: Synchronous start/operation; all BDs must be within radio range of each other; additional BDs cannot join the scatternet at a later time.
- Unknown whether resulting topology supports intended services efficiently.

Scatternet Formation Based on Mobile Agents

Our proposed solution

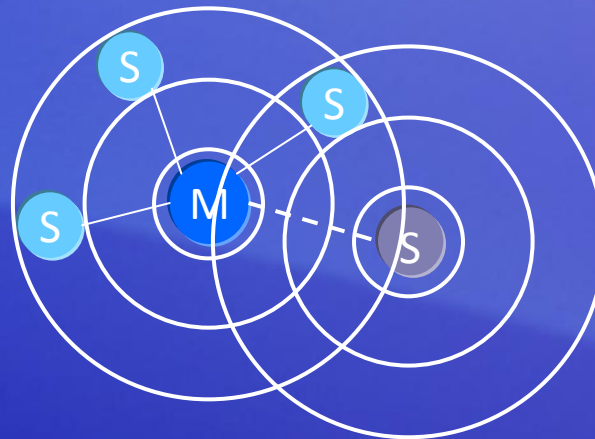


- Bluesocuts decouples device discovery from actual topology formation.
- Wave is employed to program 'light-weight' codes that implement a tree-shaped scatternet.
- Agents can accomplish this by accessing APIs that control Bluetooth's HCI to manipulate link creation/deletion.
- Relax previous assumptions.

Scatternet Formation Based on Mobile Agents

Bluescouts in action

Case 1: A Bluetooth device is discovered by a master and becomes slave



(nothing to do)

This is the simplest case. No scatternet is formed; instead, the new device joins the existing piconet.

Scatternet Formation Based on Mobile Agents

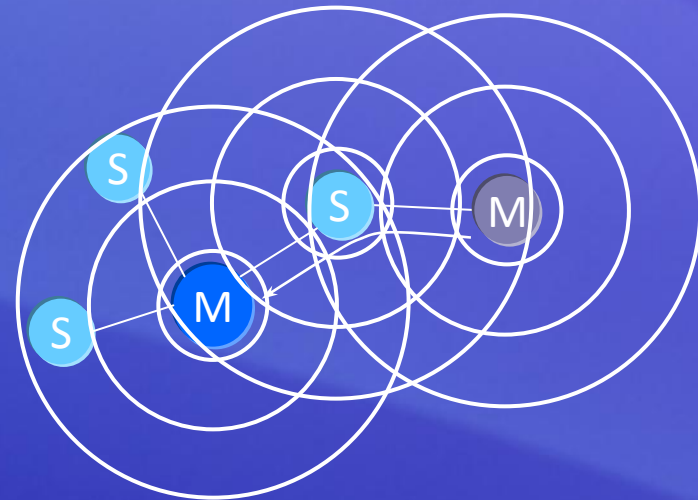
Bluescouts in action (continued)

Case 2: A BD is discovered by a slave and becomes master. Agents are launched in an attempt to reconfigure the new BD's role.



Successful reconfiguration

Or...



Unsuccessful reconfiguration

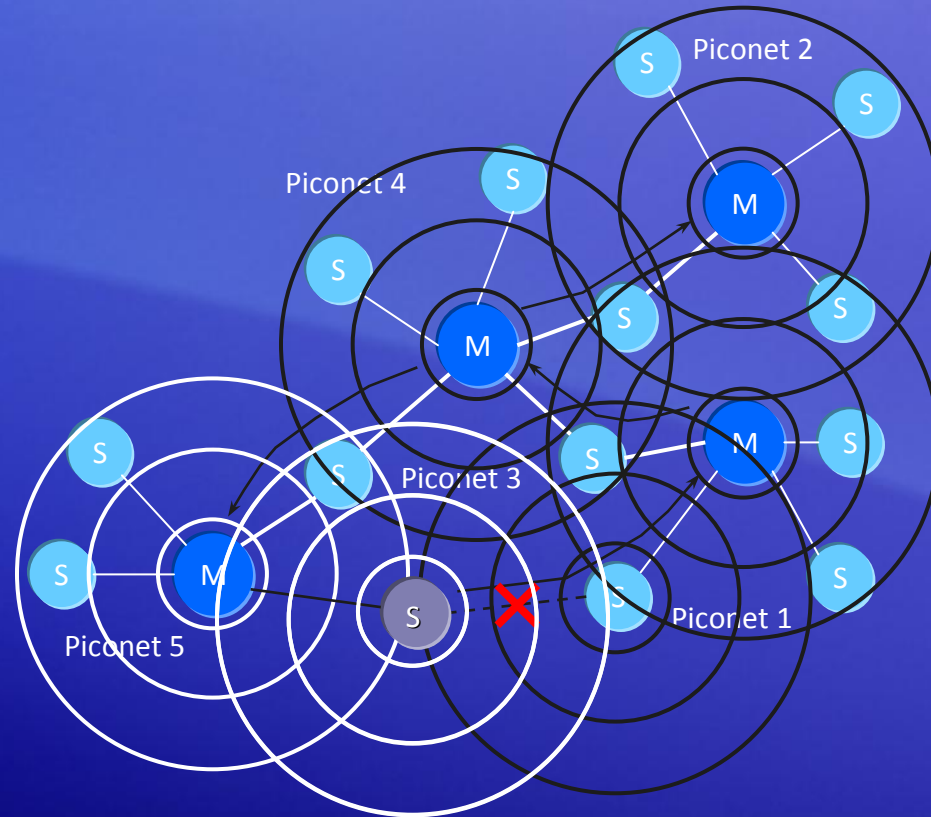
In this case a scatternet that contains two masters may be formed if the initial reconfiguration attempt fails.

Scatternet Formation Based on Mobile Agents

Bluescouts in action (continued)

Case 3: Agents conduct a distributed depth-first search in an attempt to reconfigure the new BD's role.

In this case the scatternet grows in an organic fashion as new Bluetooth devices unable to join an existing scatternet form additional piconets.



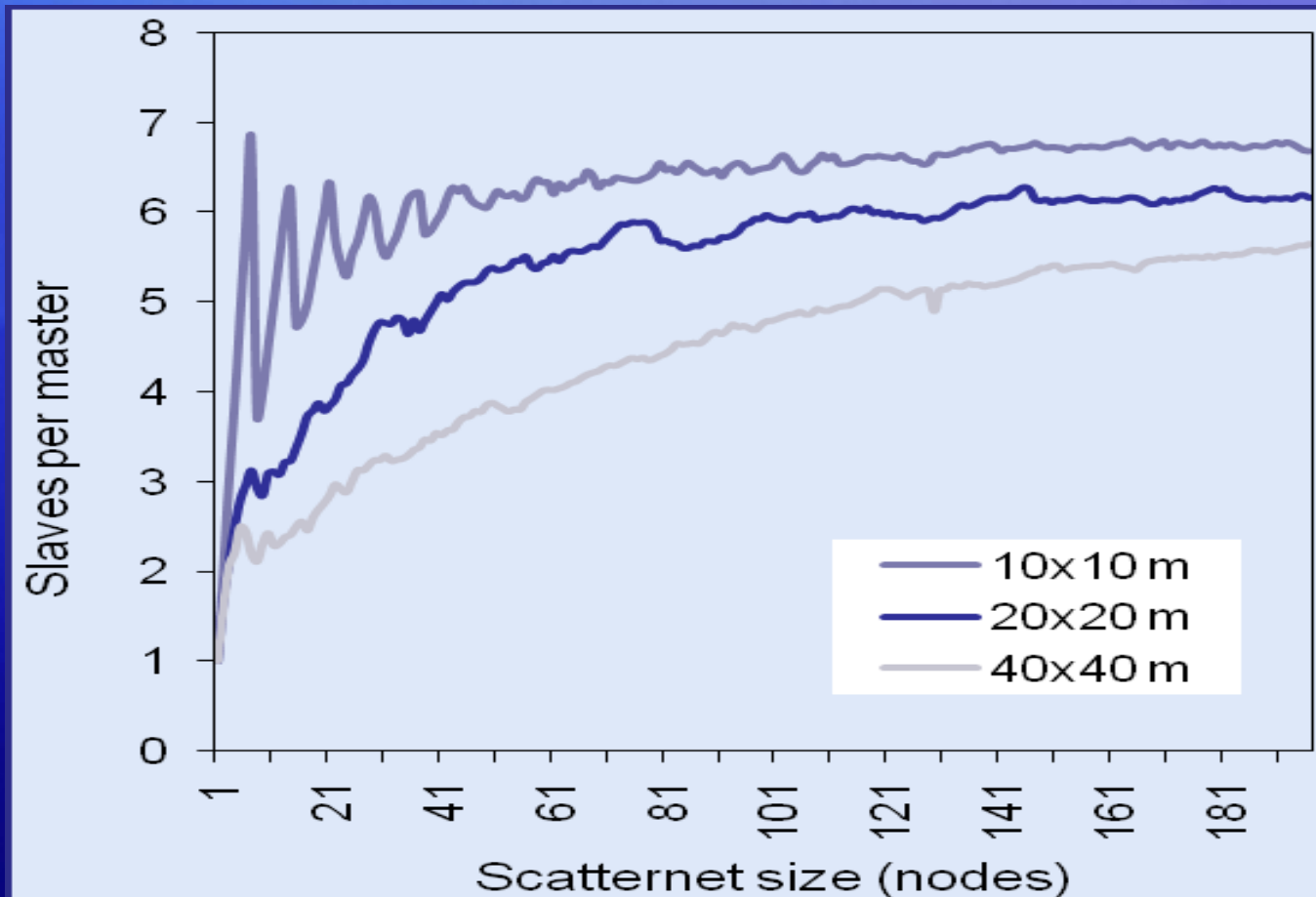
Scatternet Formation Based on Mobile Agents

Computer simulation parameters

- Devices arrive sequentially following a Poisson process.
- Devices are uniformly-distributed in the deployment area.
- Deployment areas used: 10, 20 and 40 square metres.
- Compact agents: 204 bytes long that fit within a DM5 ACL packet.
- Results averaged over 50 runs per deployment area.
- Moderately large scatternets of 200 devices.
- Used Wave's interpreter Ver. 0.9 for Linux to simulate scatternets.

Scatternet Formation Based on Mobile Agents

Computer simulation results: Slave-to-master ratios



WISEMAN: A Mobile Code Platform for Wireless Sensor Networks

Active networking in a resource-
constrained system

Mobile Agents in Wireless Sensor Networks



A case for using agents in WSNs

WSNs are specialized systems with limited capabilities that perform well-defined tasks.

WSN devices work in a coordinated manner to accomplish the intended goal. However,...

... bandwidth and power conservation are a major concern.

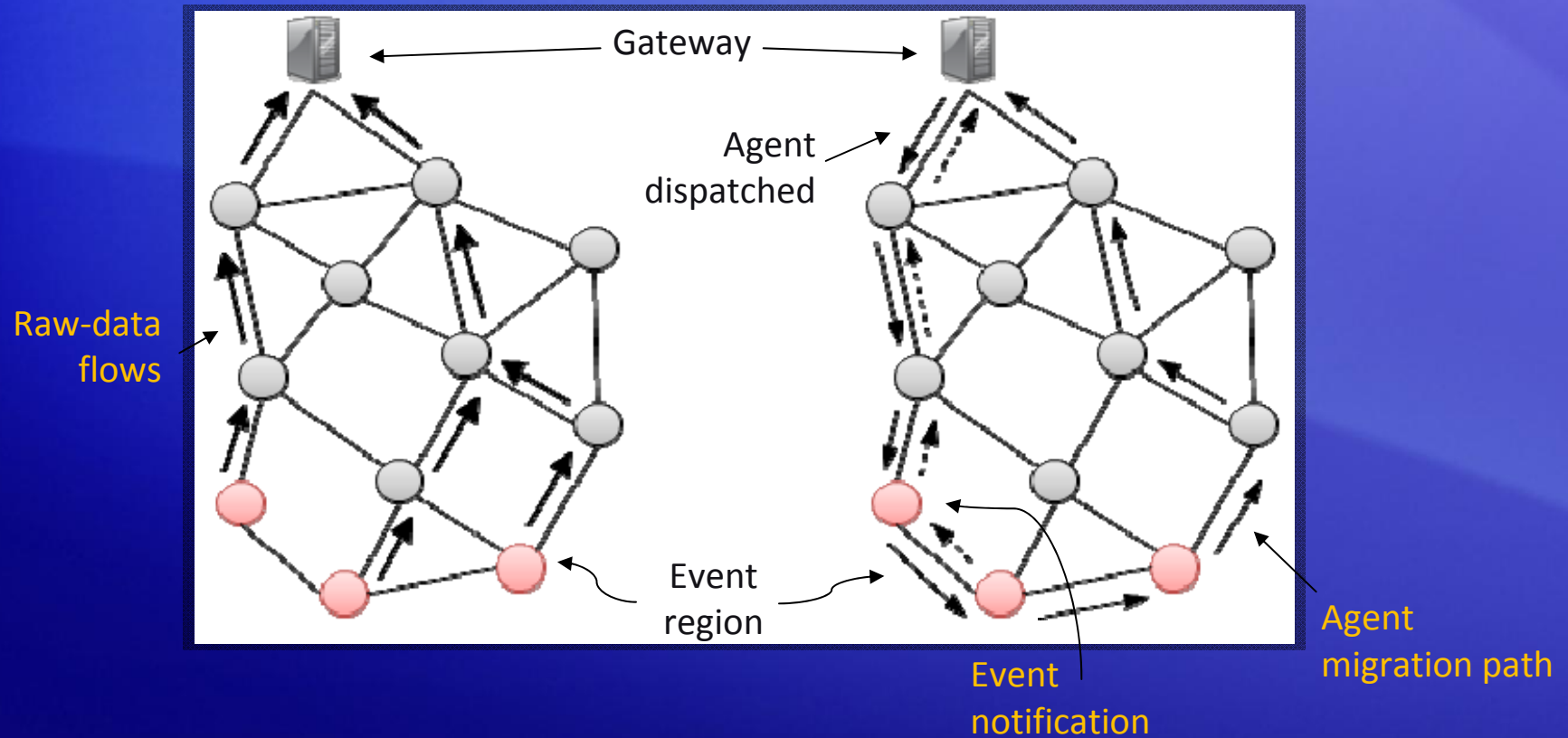
- It makes sense to provide WSN nodes with an efficient task coordination mechanism that supports the implementation of different policies.
- Programmable, lightweight agents or codes that consume little bandwidth and energy can be employed for this purpose.

Mobile Agents in Wireless Sensor Networks

Enabling programmability in WSNs

(a) Data forwarding approach

(b) Mobile Agent approach



Mobile Agents in Wireless Sensor Networks

Enabling programmability in WSNs

Message passing

vs.

Mobile agents

- Message packet has well-defined fields that cannot be changed later.
 - Message fields are inspected, and predefined actions are enacted.
 - Little or no flexibility if changes are needed – have to reprogram nodes.
 - Impractical to implement extensions or changes to the message format and processing function.
- There are only agent-defined fields; the rest of the message space is for the codes.
 - An interpreter is used to execute the codes of the agent and perform any actions.
 - Maximum flexibility – sensor nodes need not be reprogrammed.
 - No changes are needed for the interpreter unless new language constructs are defined.

Mobile Agents in Wireless Sensor Networks

Features of mobile agents

- What advantages can we obtain from using agents in WSNs?

Asynchronous and autonomous execution

Robust & fault tolerant

Overcome network latency

Reduce the network load

Dynamic adaptation

Encapsulate protocols

Naturally heterogeneous

- Compact (mobile) codes can save bandwidth
- Agent propagation delay can be shorter
- Reduced power consumption – longer-lived WSN

Mobile Agents in Wireless Sensor Networks

Binary vs. interpreted codes in WSNs

- Binary codes execute faster than interpreted codes, but they make WSN re-tasking more difficult.
- Interpreted codes facilitate WSN re-tasking, but it increases memory footprint.
- Mobile agent approach is more vulnerable to security issues.
- Mobile agent-based systems attempt to achieve a functionality balance incorporated of the code interpreter:
 - Coarse-grained: <execute task A, execute task B; finish>
 - Fine-grained: <...move to X, store M, retrieve Z, Add Z+1,...>

Mobile Agents in Wireless Sensor Networks

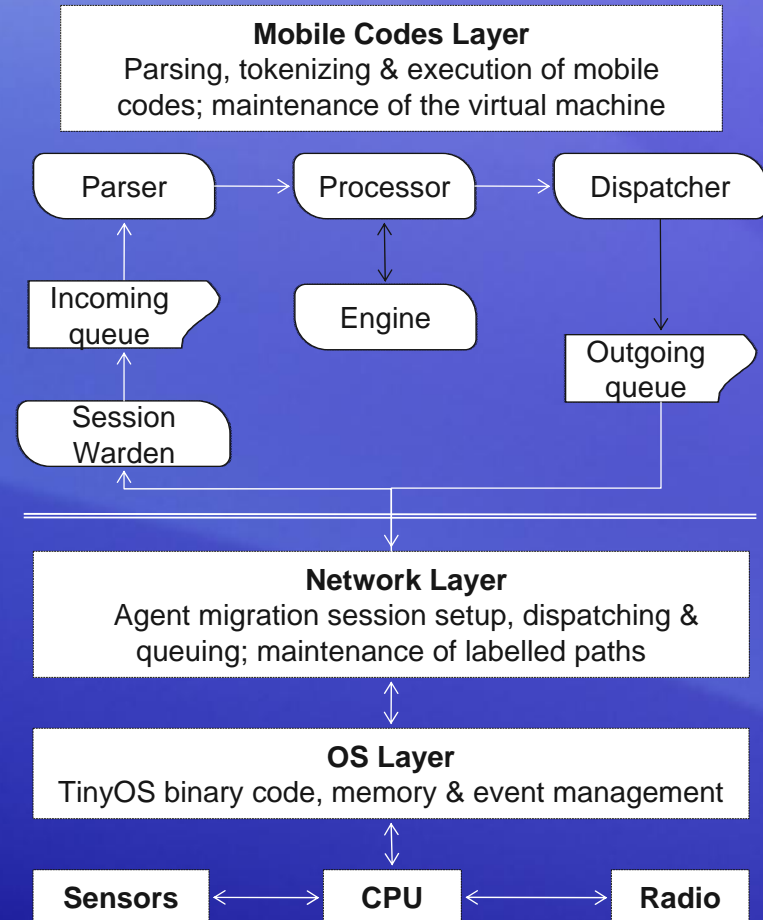
What we propose

- **WISEMAN: Wireless Sensors Employing Mobile AgeNts** – a simplified version of a much earlier mobile agent system.
 - High-level language
 - Coarse-grained functionality for distributed coordination of mobile processes, and
 - Some fine-grained functionality for local operations and condition checking
- *The actual algorithm that coordinates distributed processes is mobile.*
- Algorithms that execute repetitive tasks remain fixed at the nodes.
(Counterintuitive using mobile agents that perform the exact same task throughout the WSN.)

Mobile Agents in Wireless Sensor Networks

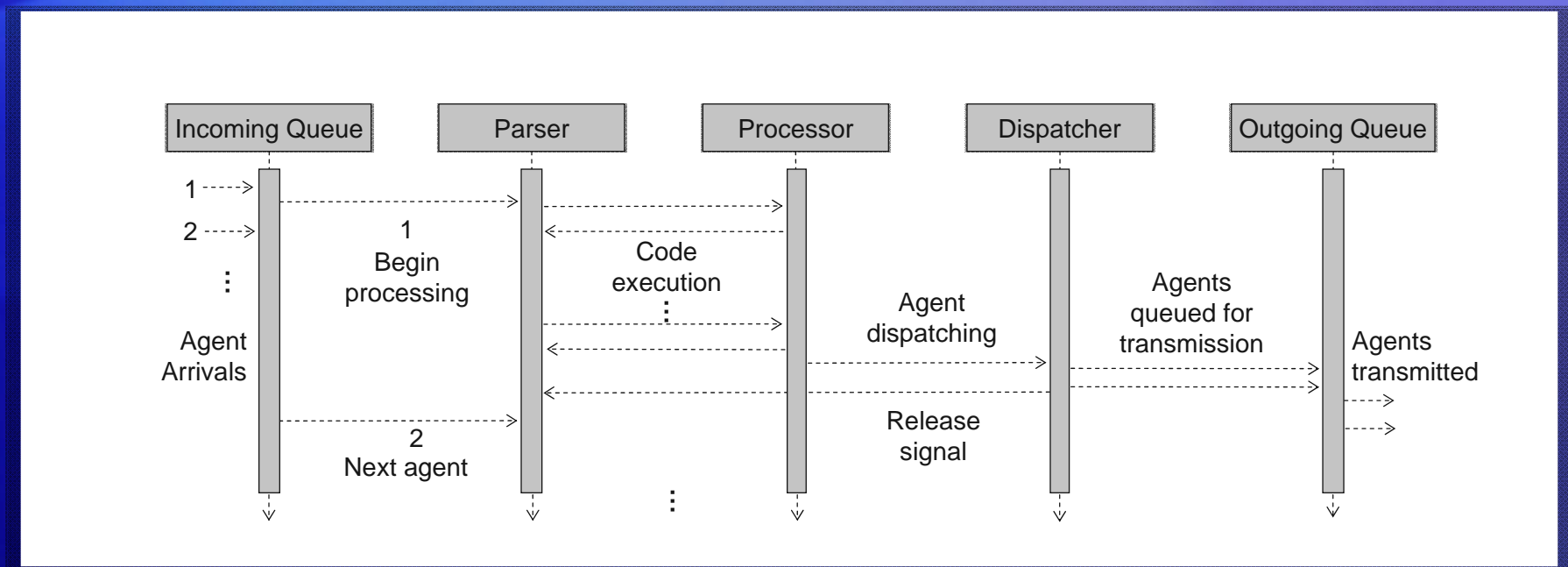
How it works

- An interpreter is installed at every sensor node to process mobile agents injected into the network.
- Wiseman relies on the underlying communications system to dispatch codes from one sensor node to another.
- Wiseman is comprised by: a parser, a processor, a dispatcher, incoming/outgoing queues, an engine, and session warden.
- The underlying OS is TinyOS.



Mobile Agents in Wireless Sensor Networks

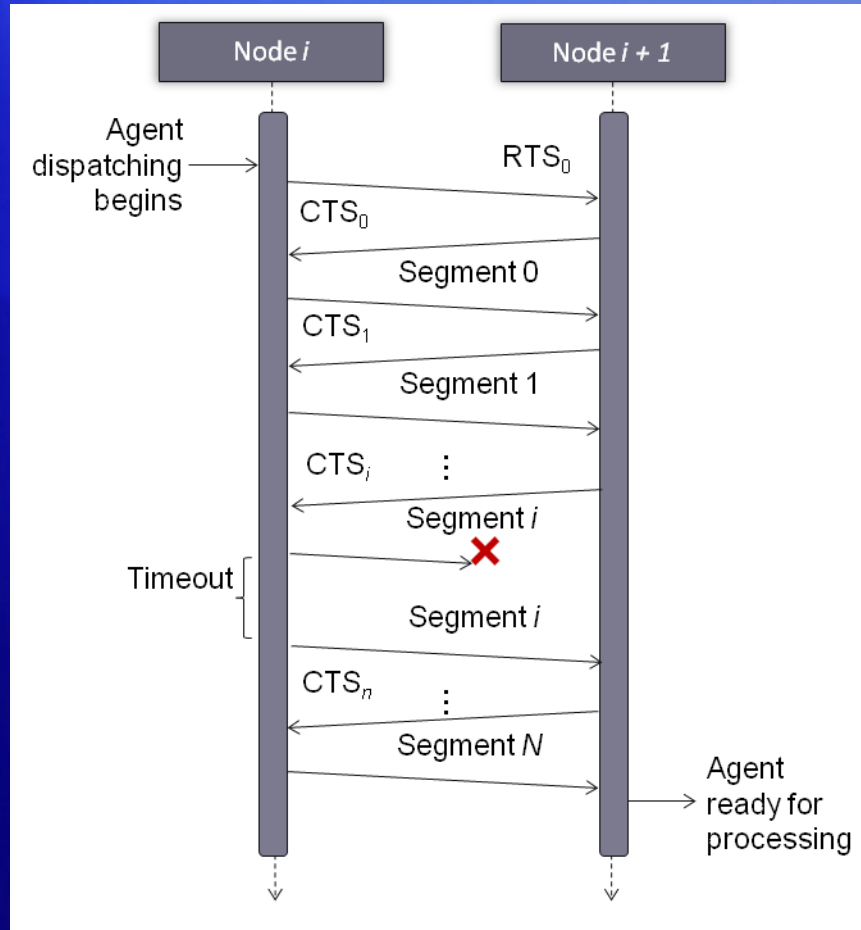
Wiseman agent execution sequence



- Wiseman agents are executed one at a time in order to simplify the architecture of the interpreter.
- Both incoming and outgoing agents are queued for processing or transmission, respectively.

Mobile Agents in Wireless Sensor Networks

Forwarding process



- A simple forwarding scheme was implemented to transfer individual segmented agents.
- Request-to-send (RTS) and Clear-to-send (CTS) signals are exchanged before packet transmissions take place.
- Some extra information is used to ensure the correct forwarding of agents.
- Agents are reassembled at the destination node before inserting them into the incoming queue.

Mobile Agents in Wireless Sensor Networks

WISEMAN features

- **Compact codes:** Short language constructs to code Wiseman scripts.
- **Metamorphism:** Agents can modify their own code. Therefore, coordination algorithms can be changed on-the-fly.
- **Virtual network creation:** Wiseman supports the creation of logical links between sensor nodes, as needed by the application.
- **Decoupled agent coordination:** Agents may communicate indirectly through local variables at the sensor nodes (shared memory access).
- **Strong mobility:** Program may suspend execution at any point, hop to another sensor node, and resume execution where it had stopped.

Mobile Agents in Wireless Sensor Networks

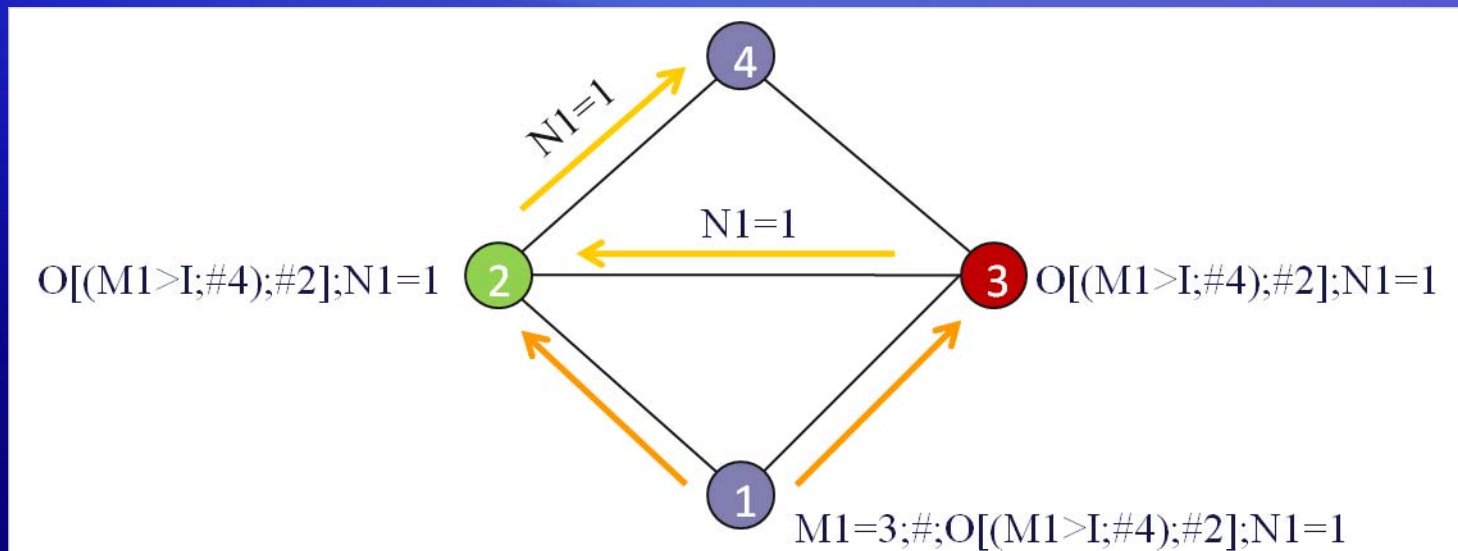
WISEMAN Instruction Set

Lexeme	Name	Type	Description
N	Numeric	Variable	Local storage of numeric values
M	Mobile		A numeric value carried by an agent form
C	Character		A character value stored locally
B	Clipboard		Temporary storage of a numerical value
I	Identity	(environmental)	Holds the local ID node value
P	Predecessor	(environmental)	Holds the ID value of the node that an agent arrived from
L	Link	(environmental)	A character value used to label virtual links
O	Or	Rule	Yields true if <i>any</i> embraced commands is executed successfully
A	And		Yields true if <i>all</i> embraced commands are executed successfully
R	Repeat		Cycles through embraced commands
+ - * / =	Arithmetic	Operators	Used to perform regular arithmetic operations on variables
< <= == => !=	Comparison		Standard operators to evaluate values and variables
#	Hop	Operator	Indicates that the agent will hop to another node or set of nodes
@	Broadcast		Broadcast agent to 1-hop neighbours
\$_	Execute		Performs local operation as indicated by parameters
!_	Halt		Stops execution with success or fail outcome as indicated
^_	Insert		Inserts locally-stored agent into the
_?	Label query		Tests whether a labelled path exists in local node
{...} [...] (...);	Semicolon	Delimiters	Used to separate individual expressions and rules

Mobile Agents in Wireless Sensor Networks

WISEMAN example

- Set mobile (private) variable M1 to 3
- Hop to all neighbouring sensor nodes
- If value in M1 is less than value of the environmental variable 'I' that holds the ID of the local node), then the agent hops to sensor node 4.
- Else hop to sensor node 2
- Set variable N1 to 1 at the sensor node reached



Mobile Agents in Wireless Sensor Networks

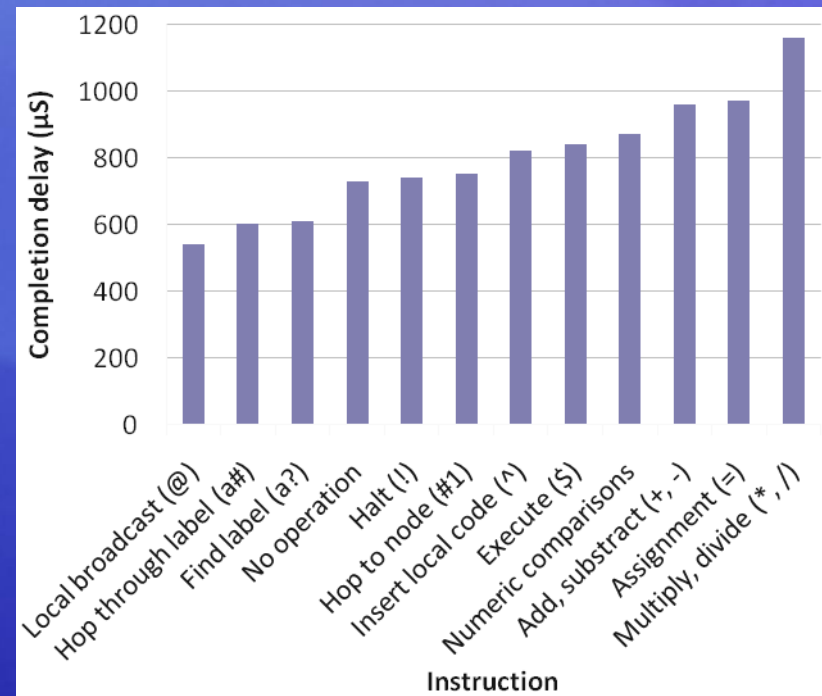
Wiseman's implementation

- Used Crossbow Technology Micaz motes
- 3V, 2.4 Ghz, IEEE 802.15.4
- Interpreter written in TinyOS v1.1
- Memory footprint = 19KBytes
- RAM usage ~ 3Kbytes
- Two queues: 3 incoming agents, 5 outgoing, 1 executing
- Max agent size = 170 bytes
- Bandwidth and delay evaluations

Mobile Agents in Wireless Sensor Networks

Performance evaluation: execution delay

- Slower than Agilla, but still reasonably fast.
- Arithmetic operations take the longest to execute
- Hop operations take the least to execute
- Average $\sim 800\mu\text{S}$



Mobile Agents in Wireless Sensor Networks

Feature comparison

Feature	Agilla	Wiseman
Memory footprint	~42KB	~20KB
RAM	3.6KB	3KB
Program type	Bytecode	Text strings
Process coordination	No	Yes
Virtual network support	No	Yes
Execution granularity	Fine	Coarse & fine
Agent cooperation	Yes	Yes
Migration strategy	Strong	Strong

Research Directions of Mobile Agents in Wireless Networks

Research on Mobile Agents in Wireless Networks

Current state of affairs

- Mobile agent applications reportedly implemented at the lab level in: Cisco, NASA, British Telecom, etc.; and previously at Siemens and Ericsson.
- First reports of mobile agent research in wireless networks around 10 years old.
- Their usefulness depends on many factors. However, some of the most compelling applications also pose the biggest security problems. (Can I run my software in your computer?)
- Security problem is two-fold: malicious agents, or malicious hosts.
- Agent system architecture depends on the specific application.
- One-size-fits-all approach is overkill.

Research on Mobile Agents in Wireless Networks

Possible future directions

- Solving security issues will continue being priority #1.
- Mobile agent applicability in infrastructure-free wireless networks (ad-hoc, WSN, vehicular) targeted primarily at network management. This simplifies agent system architecture, and averts some security issues.
- Research on distributed process coordination becomes crucial. How should agents cooperate to achieve a particular task?
- Many variables: underlying system environment, available resources, decision policies, etc. How to manage such diverse factors in a harmonized fashion?
- Artificial intelligence approaches increasingly appealing: supervised learning, un-supervised learning, reinforcement learning ...



Thank you!

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