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

- 100 years old in 2008
- A world class university at a spectacular location
- Consistently ranked among world’s top 50 universities (#26, Newsweek 2006; #36, Shanghai Jiaotong 2007)
- Annual budget of $1,600,000,000
- More than 45,000 students
- 12 faculties and 11 schools, 2 campuses
- 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
54 faculty members, 10 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*
Overview of Short-Range Wireless Communications

WPAN and WSN
Overview of Short-Range Wireless Communications

• WLANs have become a pervasive means portable PCs to connect to the Internet and for other networking applications (e.g., home, office, etc.)

• However, 802.11x radio incurs relatively high power consumption that is unsuitable for portable handheld devices. Plus, it does not address application-layer issues.

• New technologies were introduced earlier in this decade to cope with these issues: Bluetooth and ZigBee.

• Other technologies exist: Wibree, RFID, etc.

• Wide applicability range: home, industrial, medical, environmental, vehicular, etc.
Overview of Short-Range Wireless Communications

<table>
<thead>
<tr>
<th>TEXT</th>
<th>GRAPHICS</th>
<th>INTERNET</th>
<th>HI-FI AUDIO</th>
<th>STREAMING VIDEO</th>
<th>DIGITAL VIDEO</th>
<th>MULTI-CHANNEL VIDEO</th>
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<tbody>
<tr>
<td>SHORT &lt; RANGE &gt; LONG</td>
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<tr>
<td>ZigBee</td>
<td>Bluetooth</td>
<td>Ultrawideband</td>
<td>802.11b</td>
<td>802.11a/g</td>
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<td>WLAN</td>
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<td>PAN</td>
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<tr>
<td>LOW &lt; DATA RATE &gt; HIGH</td>
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Bluetooth and ZigBee cater to networking applications in which relatively lower-rate data communications at short ranges are sufficient.

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

Ultra-wideband emerging to support high data rate at low power consumption.

Ref: IEEE 802.15-03/305r0
Overview of Short-Range Wireless Communications

**Bluetooth**

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

Promoted by a multi-company consortium.

- Reduced power consumption when compared to 802.11x.
- Version 2.1 supports data rates of 3 Mbps, but Ver. 3.0 will incorporate UWB technology that can support data rates of up to 480 Mbps.
- ULP Bluetooth based on Wibree 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.

- Data rates in the range of 10k-115 Kbps; and ultra-low power consumption that extends battery life that ranges from a few months to a few years depending on the application.

- Less popular than Bluetooth, but gradually gaining acceptance.
Overview of Short-Range Wireless Communications

• Bluetooth and ZigBee-enabled devices now widely available for a range of consumer and industrial applications.

• Still a number of issues remain that are being 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 adaptiveness and reconfigurability in 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; 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 mobile agent is a type of code where mobility is an attribute incorporated into it, which is supported the underlying system.
- Mobile agents require a code interpreter.
- 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

**Collaborative learning agents**: several agents work together to accomplish a task based on a learned policy.

**Smart agents**: One or more agents work independently and without external input to accomplish a task based on a learned policy.

**Collaborative self-contained agents**: Several agents work together and without external input to accomplish a task based on a preset policy.

**Smart collaborative agents**: several agents work together and without external input to accomplish a task based on a learned policy.
Mobile Agents and Mobile Codes

At UBC, we have employed the \textit{Wave} system for the distribution of mobile codes in several active networking projects.

- The Wave system facilitates the spatial coordination of a distributed task by employing a mixture of diverse communications models, ranging from message passing to full code mobility.

- Wave is more of a mobile-code platform rather than a mobile agent platform, but it can be used to mimic some of the behaviour attributed to mobile agents.

- Wave codes can be best viewed as a programmable middleware that efficiently supports active networking.
Mobile Agents and Mobile Codes

Propagation of Wave agents

Computer A injects a Wave agent into the network. Wave interpreters communicate to propagate the codes.

1. Wave head (Sector 1)
2. Echo
3. Wave tail (Sector2.Sector3)

Computer B received the codes and executes the rest of the scripts as instructed.

• Wave agents migrate from host to host in a sequential, self-depleting fashion.
• Wave agents instruct the corresponding interpreters how to coordinate the distributed process being run as needed.
• Wave Interpreters employ existing programs at the hosts to accomplish other tasks.
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

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**
- **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

- **10×10 m**
- **20×20 m**
- **40×40 m**
Conclusions

• First mobile agent-based scatternet formation protocol.

• Agent approach helps decouple scatternet formation from device discovery, facilitating topology reconfiguration without performance penalties.

• Performance evaluations of Bluescouts match those published in the existing literature.

• Agent approach enables fully asynchronous protocol operation and eliminates constraints observed in existing schemes.

• *Programmable* approach introduces unmatched flexibility: any topology formation policy can be implemented.

Active networking in resource-constrained systems
Mobile Agents in Wireless Sensor Networks

A case for using agents in WSNs

Unlike general-purpose wireless networks, WSNs are specialized systems with limited capabilities that perform well-defined tasks autonomously.

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

Both bandwidth and power conservation are a priority.

- It makes sense to provide WSN nodes with an efficient task coordination mechanism that supports the implementation of multiple 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

Approach #1: Binary code distribution

- Binary codes from the WSN gateway are distributed to the rest of the nodes.
- The nodes’ memories are flashed and new images stored.
- Adds a certain degree of flexibility to the WSN.
- This is an example of mobile codes, but these are not mobile agents.
- Existing systems: Maté, Impala, Deluge.
Mobile Agents in Wireless Sensor Networks

Enabling programmability in WSNs

Approach #2: Mobile scripts

- A code interpreter is loaded into the notes.
- Agents’ codes are interpreted upon arriving at a nodes.
- Agents specify where to hop and what to do next.
- Adds improved flexibility to the WSN.
- Existing systems: SensorWare, Smart Messages, Agilla
Mobile Agents in Wireless Sensor Networks

Binary vs. interpreted codes

• Binary code executes faster than interpreted code, but makes WSN re-tasking more difficult.

• Interpreted code facilitates WSN re-tasking, but it increases memory footprint.

• Interpreted code approach is more vulnerable to security issues.

• Mobile agent-based systems attempt to achieve a balance of functionality incorporated into the actual code interpreter.
  
  • Coarse-grained: <execute task A, then 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 condensed version of Wave.
  - High-level language
  - Coarse-grained functionality for distributed coordination of mobile processes, and
  - Some fine-grained functionality for local operations
- The actual algorithm that coordinates distributed processes is mobile.
- Algorithms that execute repetitive tasks remain fixed at the motes. (Counterintuitive having mobile codes 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 codes injected into the network. WISEMAN relies on the underlying communications system to dispatch codes from one sensor node to another.
Mobile Agents in Wireless Sensor Networks

WIESEMAN agent execution sequence

Agent Queue → Parser → Execution → Dispatcher

Agent Arrivals: 1, 2, ..., N

Agent Departures

WISEMAN interpreter
Mobile Agents in Wireless Sensor Networks

WISEMAN features

- **Compact code**: Short language constructs to encode information into WISEMAN scripts.

- **Metamorphism**: WISEMAN allows agents to self-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 example

• Set mobile (private) variable M1 to 3
• Hop to all neighbouring sensor nodes
• If value in M1 is less than value in local variable N2 (holding the ID of the local node), then hop 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

Accomplishments

- Functional beta version of WISEMAN.
- Core features supported by the interpreter.
- Programmed in NesC; runs on TinyOS V1.1.
- Tested on Crossbow® Micaz.
- Files can be downloaded from:

  http://www.ece.ubc.ca/~sergiog/wiseman
# Mobile Agents in Wireless Sensor Networks

## Feature comparison

<table>
<thead>
<tr>
<th>Feature</th>
<th>Agilla</th>
<th>WISEMAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Memory footprint</td>
<td>~42KB</td>
<td>~20KB</td>
</tr>
<tr>
<td>RAM</td>
<td>3.6KB</td>
<td>2KB</td>
</tr>
<tr>
<td>Program type</td>
<td>Bytecode</td>
<td>Text strings</td>
</tr>
<tr>
<td>Process coordination</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Virtual network support</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Execution granularity</td>
<td>Fine</td>
<td>Coarse</td>
</tr>
<tr>
<td>Agent cooperation</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Migration strategy</td>
<td>Strong</td>
<td>Strong</td>
</tr>
</tbody>
</table>

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The International Wireless Communications and Mobile Computing Conference, Crete Island, Greece, August 6-8, 2008
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 remain 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!

www.ece.ubc.ca/~vleung