Service and Resource Discovery in Smart Spaces Composed of Low Capacity Devices

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Outline

- ***Introduction and Problem Description***
- Proposed Solution
- Experimental Results
- Conclusions and Future Work

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Smart Spaces

- Smart Space: a (living) space with
  - embedded technology...
    - 'regular' CE & computing devices
    - smart nodes: sensing, actuating, communicating, computing
  - ...that is networked...
    - wireless, mostly
  - ...designed to collaborate and share...
  - .... to interact with / serve users...
    - maximum autonomous operation
    - provide services with minimal user effort
  - ... and the electronics these users carry
    - e.g. body sensor networks, personal electronics

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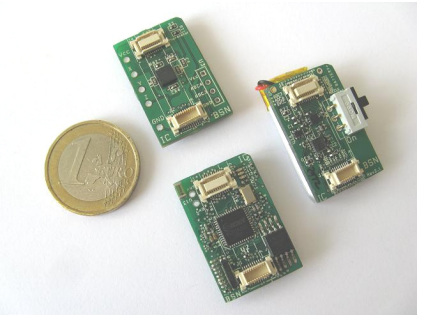
Low Capacity Devices

- Sample specifications:
  - CPU: 1-25 MHz clock frequency
  - 1-10 kilobytes of RAM / 1-128 kilobytes of programmable ROM
  - Communication device: Frequency band 433 MHz – 2.4 Ghz
  - 2.0 – 2.5 Ah for an AA size battery
    - perhaps much smaller even
  - sensors, actuators

- Example: Wireless Sensor Network
  - networks of cheap and 'intelligent' sensors.
    - Representative of 'low-capacity device' class
    - Naturally pervasive: automatic operation, seamless integration, collaboration
  - but: little energy
  - and: small packet sizes, bit rates



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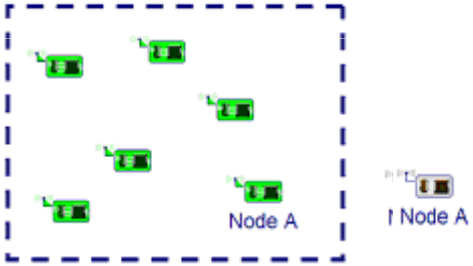
Smart Space Architectures

- Many SS architectures are heavy-weight!
  - layered architectural design for the sake of abstraction (suboptimal)
    - messaging overheads, increased energy usage.
  - State-of-the-art frameworks (e.g. OSGi, NoTA-M3) have high resource requirements.
    - Execution platform, message (xml) size and interpretation overhead
    - Implicit assumption: SS network is composed of relatively high capacity nodes (e.g. laptop computers, mobile phones, PDAs).
- Unusable directly with low capacity nodes (e.g. WSN nodes)
  - energy, computational power, network bandwidth limitations.
  - needs gateways/proxies
    - configuration overhead, reliability
    - latencies

Fundamental requirements

- Smart Space requirements
  - *programmable and configurable* – wished behavior can be imposed
  - *sharing of services* – by concurrent (distributed) applications
  - *separation of coordination and service* – separate application logic from device functions
  - *integration with the regular IP infra structure*

- Basic functionalities provided by nodes to *the network*
  - *Code load* – to define services, configuration
  - *Discovery* - detection of nodes, services, resources
  - *Service/Resource Monitoring & Management*
  - *Service composition/coordination*– by third party



- Lightweight architecture: how to provide this with low-capacity nodes?
  - This work focuses on example of service/resource discovery and monitoring:
    - Node is discovered (registered to the system)
    - Node is monitored (report introspection information)

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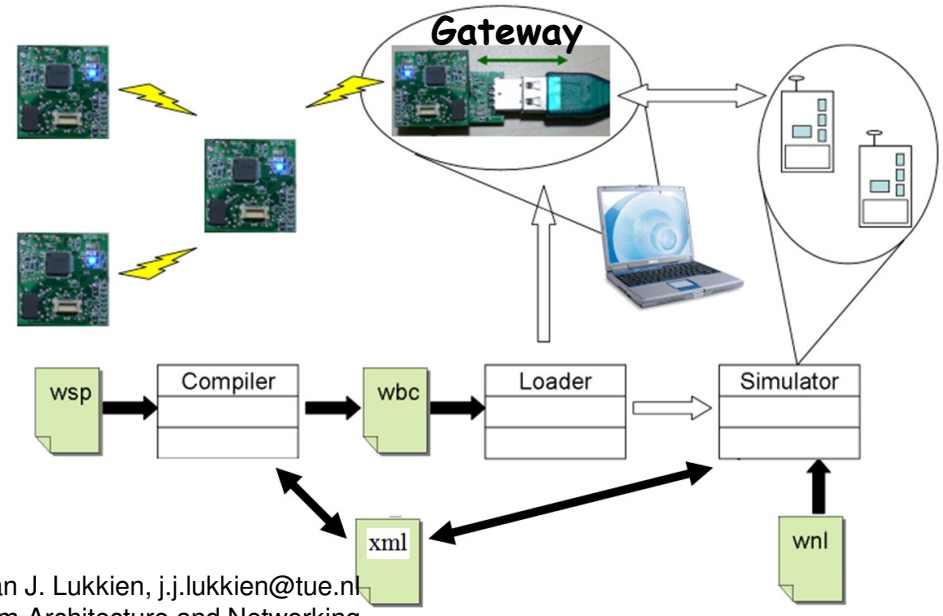
Baseline Architecture: OSAS Framework

- Open Service Architecture for Sensors (OSAS)
  - *language, to program the entire network ('macro-programming')*
    - *with concepts of a service, eventing and subscription*
    - *and* content-based *addressing*
  - *runtime system contains virtual machine (byte code)*
    - *has access to a set of system calls (OS-provided functions)*
  - *message format*

- Four components
  - *Compiler*
  - *Loader*
  - *Runtime system*
  - *Simulator*
    - runs same runtime system



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OSAS Framework: *Programming Model*

- Nodes run services:
  - A service has event *generators* and event *handlers*.
  - A link between a generator and a handler is called a *subscription*.
  - Interaction between services by a *asynchronous remote procedure call*
    - upon firing of the event
    - or simply as part of a handler

- Supported by WASP Service Composition Language (WaSCoL)
  - Specification of services with event-condition-action rules
  - Composition of services (i.e. subscriptions)
  - Use content-based addressing to associate node with service
  - *Programs can be developed and loaded incrementally*

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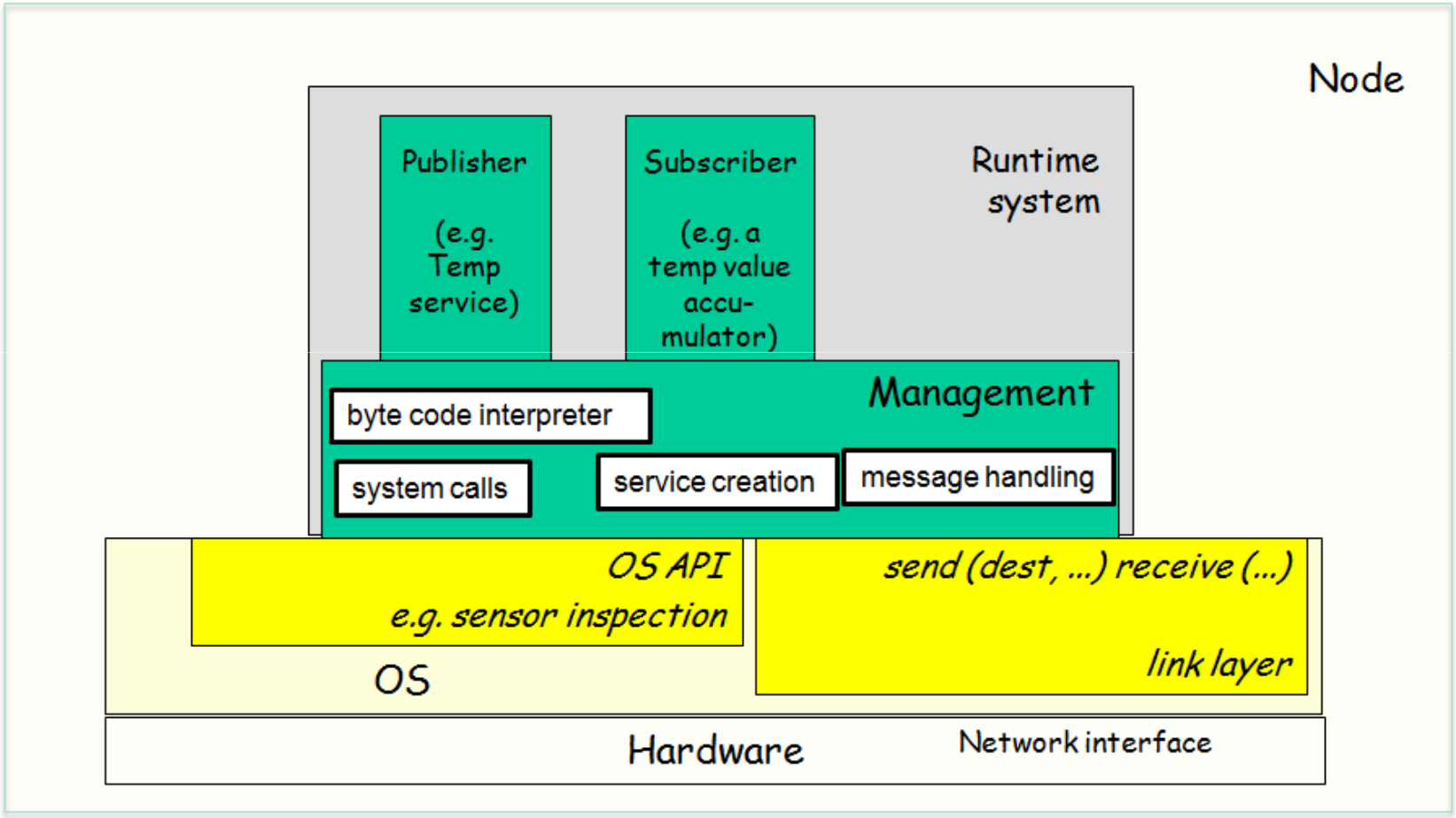
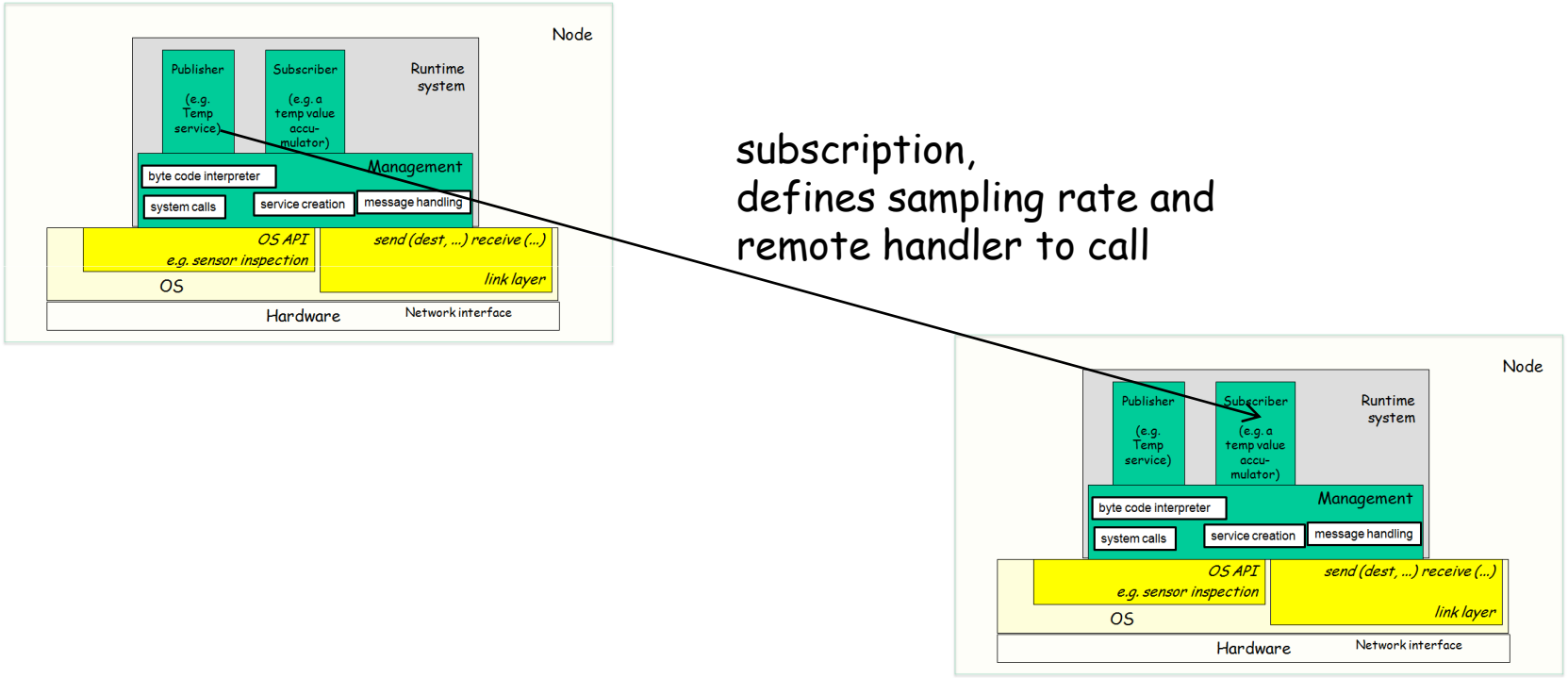
Run-time organization



Connection by subscriptions



OSAS Framework: *Messaging and Communication*

- Communication:
  - *SendToSubscribers()*, in case event 'fires'
  - *Send()* – i.e. aRPC in local neighbordhood
  - Two implicit routing methods:
    - Flooding, to transmit installation messages
    - Point-to-point: route is setup via a subscription
  - application-level routing
- Message format – asynchronous remote procedure call
  - Header; (Handler, arguments) series
  - can be bound to MAC, or other carriers (e.g. UDP)

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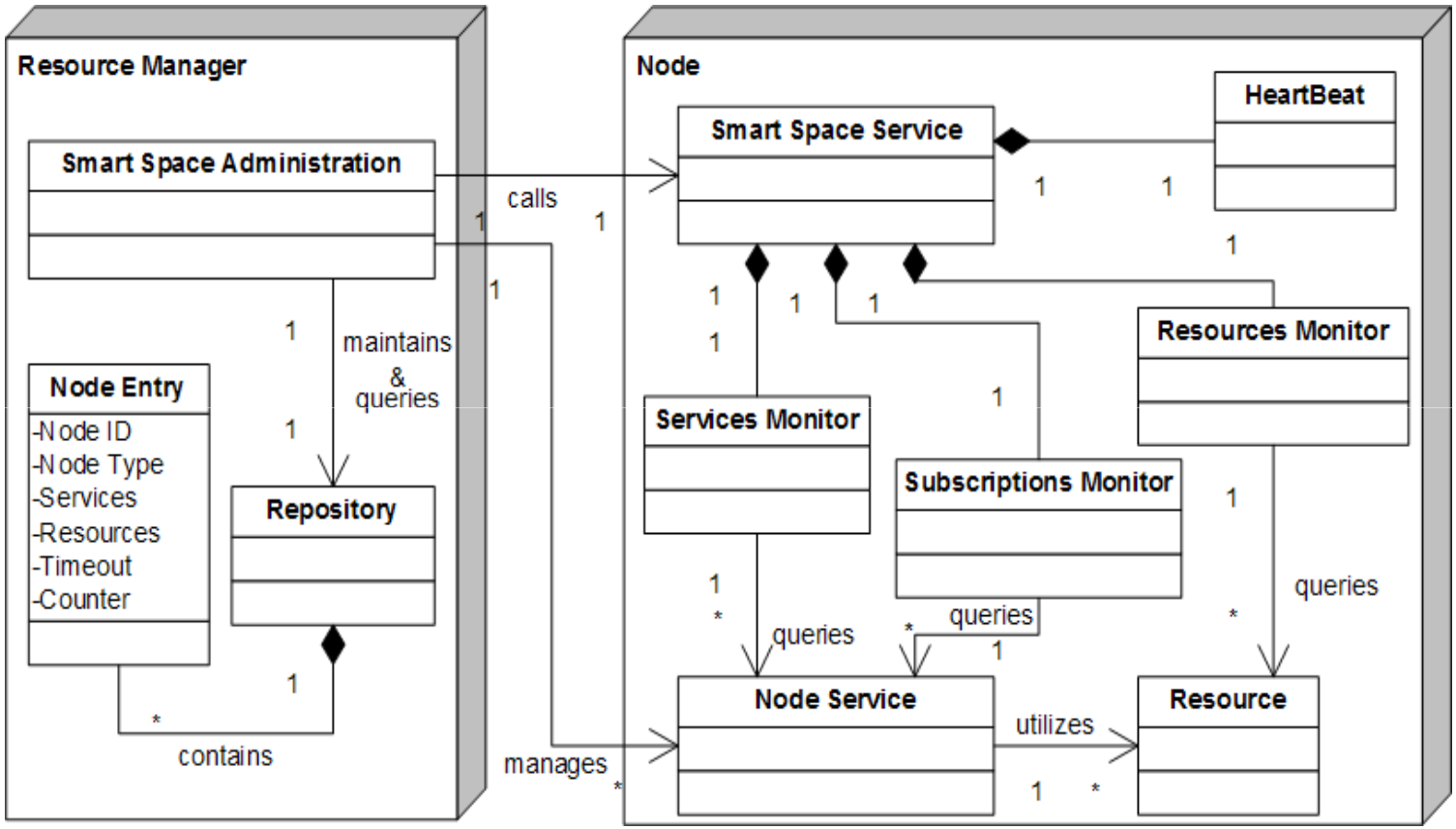
Example: Smart Space Management

- Given: a network running an OSAS application
- A resource manager (RM, special node) wants to
  - know which nodes exist
  - which services these run and subscriptions they have
  - which resources are available on these nodes
    - memory, battery, ...
- RM may make this information available again as a service, or use it for taking *mapping decisions*

Smart Space Management Architecture



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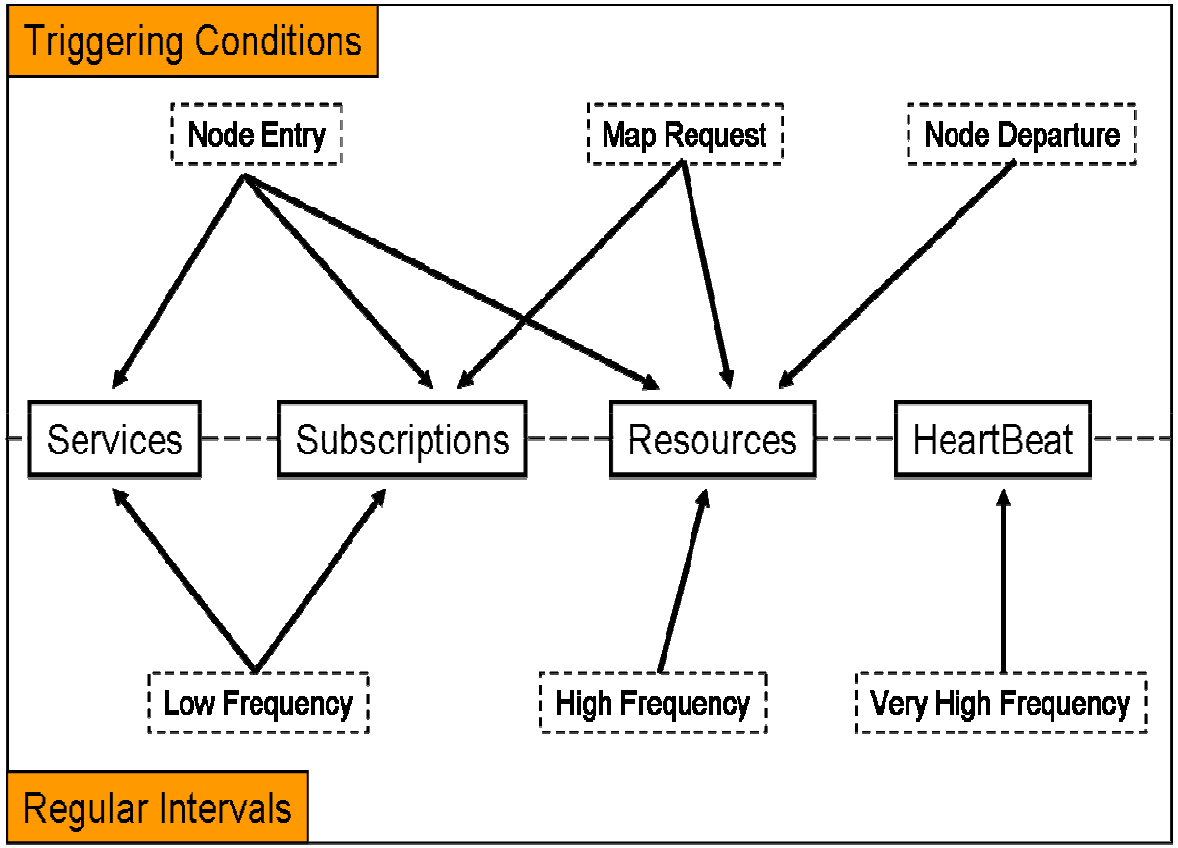
Service/Resource Monitoring: *Reporting Intervals & Triggers*



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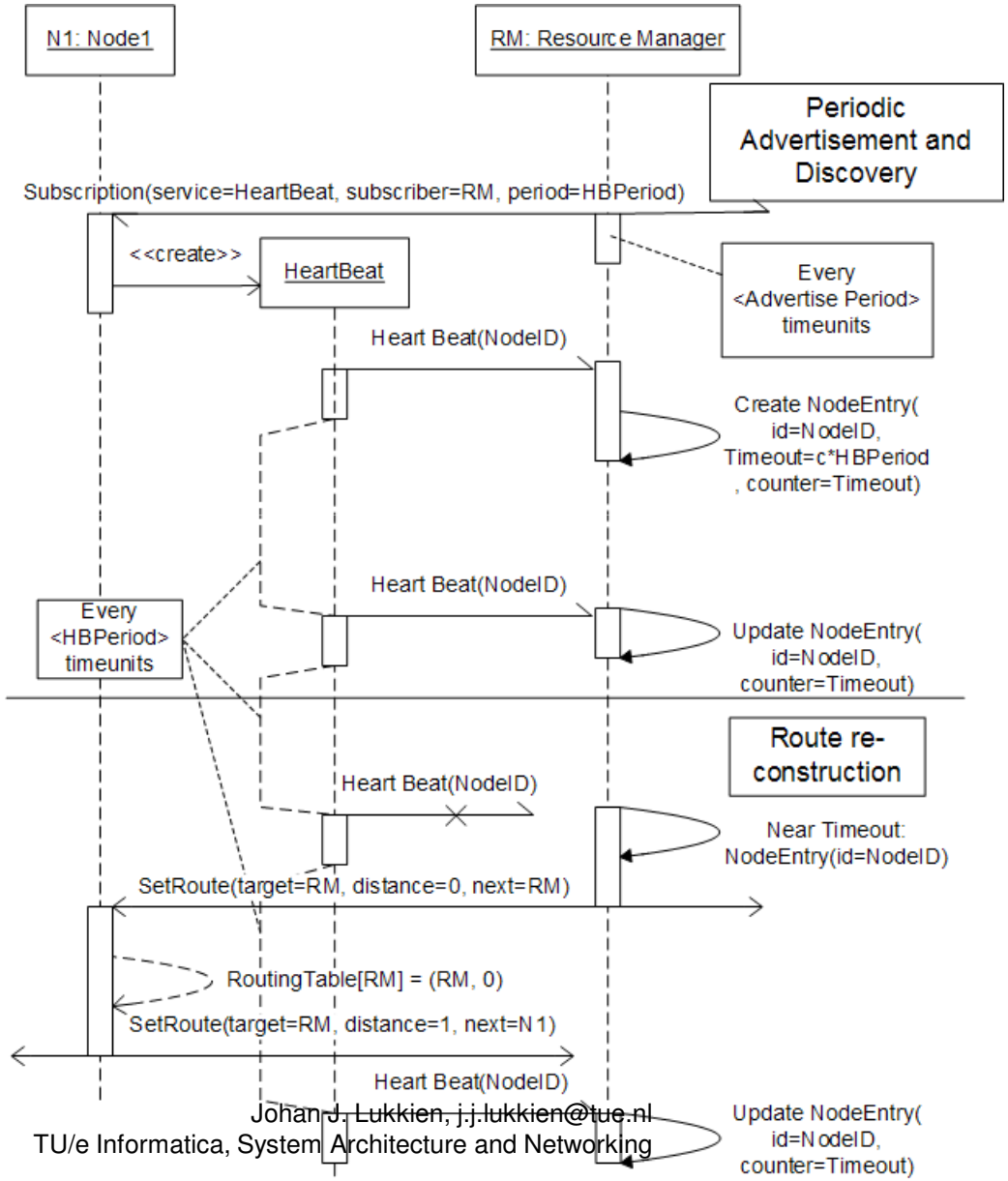
Implementation

- Management functionality is implemented *as (part of) an OSAS application*
  - Node discovery:
    - RM regularly subscribes to a heartbeat service of all nodes (in fact: advertises itself in this way)
    - result: RM receives regular heartbeat indicating nodes' presence
      - first is used to register node
  - Path reconstruction due to mobility
    - Regular subscription solves this
    - RM may subscribe to specific node after some heartbeat misses
      - or just reconstruct the route ('setroute')
  - Service & resource discovery:
    - part of heartbeat response message
    - frequency of resource reporting and service reporting as extra parameter of subscription, or as additional subscriptions
  - RM may inject those services itself

Service Discovery & path maintenance

- Periodic advertisement

- Conditional route reconstruction



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Example Scenario

Example scenario with the following parameters:

Parameter	Value
HeartBeat Period	**1 second**
Timeout Period	**6 seconds**
Route Fix Trigger	**3 seconds to timeout**
Max. Route Fix Frequency	**every 3 seconds**
Refresh Registry Period	**1 second**
Advertisement Period	**10 seconds**
LowFrequencySubscription Period	**60 minutes**
HighFrequencySubscription Period	**30 seconds**
Triggering Conditions Check/Response Period	**1 second**

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Example Scenario: *Messaging Calculations*

Sent Messages	Received Messages
HeartBeat: 60	**Advertisement: 6**
Report Resources: 2	**Resource Report Subscription: 2**
Report Services: 1/60	**Services Report Subscription: 1/60**
Report Subscriptions: 1/60	**Subscriptions Report Subscription: 1/60**
***Total:* ~ 62**	***Total:* ~ 8**

Message Count of Regular Interval Messages (per minute)

	Sent Messages	Received Messages
Node Entry	**3**	**3**
Set Route	**1**	**1**
Node Departure	**1**	**1**
Service Mapping	**2**	**2**

Message Count of Triggering Conditions Messages (per occasion)

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Deployment on Physical Nodes

	ROM **(in bytes)**	RAM **(in bytes)**
TinyOS (w/o OSAS)	**15912**	**947**
TinyOS (w/ OSAS)	**28068**	**1289**

Footprint of TinyOS and OSAS

Service	Size **(in bytes)**
HeartBeatService	**28 (14 ROM + 14 RAM)**
ReportServicesService	**30 (16 ROM + 14 RAM)**
ReportResourcesService	**30 (16 ROM + 14 RAM)**
ReportSubscriptionsService	**30 (16 ROM + 14 RAM)**
Total	***118 (62 ROM + 56 RAM)***

Footprint of Smart Space Application

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Deployment on Physical Nodes

- Message header size:
  - MAC protocol (10 bytes)
  - OSAS messaging protocol (5 bytes)

Message payload sizes (assuming 8-bit encoding):

Message	Size **(in bytes)**
HeartBeat Report	**2**
HeartBeat Subscription	**17**
Services Report	**3 + (# services)**
Resources Report	**2 + 2 * (# resources)**
Subscriptions Report	**2 + 4 * (# subscriptions)**
Services Report Subscription	**17**
Resources Report Subscription	**17**
Subscriptions Report Subscription	**17**
Service Mapping	**9**
Service Request Subscription	**17**

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Conclusion

- Platform for Smart Spaces, as well as for general sensor networks
  - powerful primitives with little overhead
  - runtime platform
- Node discovery, Service Discovery and Resource monitoring as just another application
  - Heartbeat protocol with enhancements
  - small overheads, given the platform exists
- Service/Resource Monitoring: Classification of information types and reporting intervals-triggers
- Low footprint values, fully operational

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Future Work

- Multiple RMs that synchronize
  - reliability, distributed control
- Reduce footprint further
  - remove OS
  - can reduce ROM with 10k, RAM with 0.8K
- Monitoring mechanism:
  - Remove redundant information delivery.
  - Timing durations set by individual nodes.
  - Timing adjustments according to the dynamicity of the network.
- Management mechanism:
  - Implement service *recovery* (remapping).
  - Provide advanced service mapping and arbitration.
  - Use aggregation to reduce #messages.

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