On Smart Spaces

Status and Challenges in the Programming of sensor networks

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System Architecture and Networking

Eindhoven University

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System Architecture and Networking

Coordinated Applications | Predictable Platforms | Embedded Computations

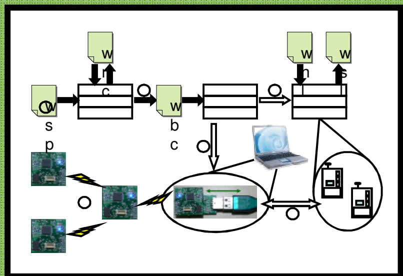
Resource-constrained networked embedded systems

content queries on security movies

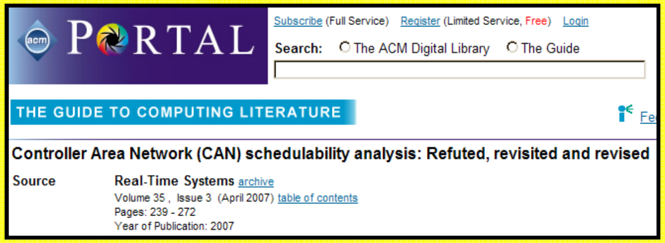
QoS for multimedia in home networks

monitoring herd behavior

IST WASP



toolchain for macro-programming



Controller Area Network (CAN) schedulability analysis: Refuted, revisited and revised

Source: Real-Time Systems archive
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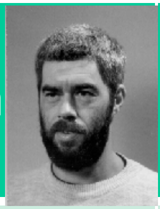
Johan Lukkien 	**Kees van Berkel** 	**Antonio Liotta** 	**Rudolf Mak** 	**Reinder Bril** 
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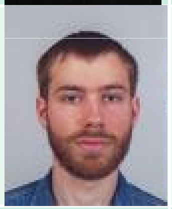
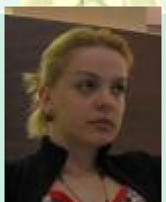
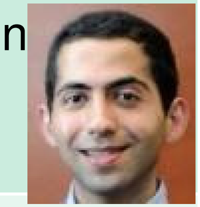
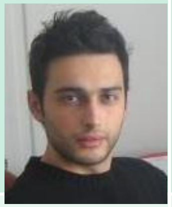
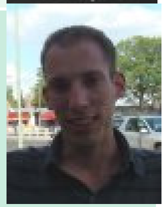
Richard Verhoe-ven 	Melissa Tjiong 	Remi Bos-man 	Waqar Aslam 	Mike Holen-derski 
Natasa Jovano-vic 	Shervin Haji Amini 	Ugur Keskin 	Sachin Bhard-waj 	Martijn van den Heuvel 
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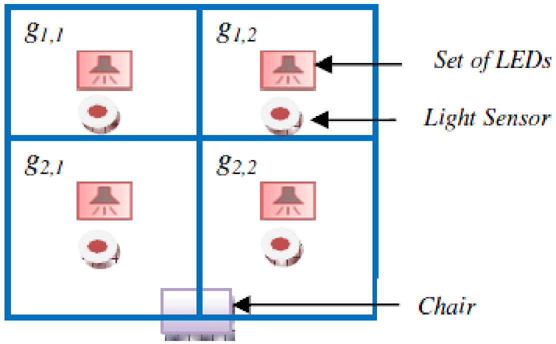
Smart Spaces

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

Examples

- Lighting:
  - adaptive lighting
    - preferences coming from user, automatically brought into the space
  - lights as output medium
    - e.g. warning, from outlook appointment



Sachin Bhardwaj, Tanir Ozcelebi, Johan Lukkien, *Smart Lighting Using LED Luminaries*, IEEE PerCom SmartE 2010.

- Sensing:
  - gesture recognition, voice commands
    - to control elements (actuators) in the space
    - to use as input media for private purpose
  - long-term monitoring
    - patient observation, elderly monitoring

Scenarios in a smart space

- Focus not just on functionality
  - given enough time and money we can make just about anything

Can we make system components such that future, as yet unforeseen, cooperations and adaptations are simply realizable, and actually work?

- Include *change* scenario's, e.g.,
  - new devices / users enter the space
    - how to understand the messages?
    - how to generate and install new functionality (e.g. automatically and invisibly coming from/to the new device)
    - how to become part of the space?
  - several users sharing a device
    - how to manage this sharing? access control?
  - saving energy

Smart space 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*

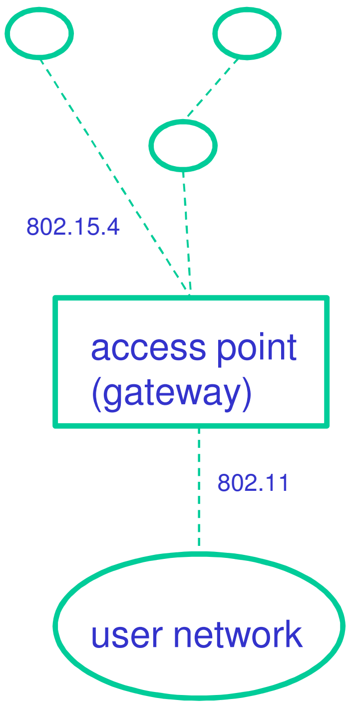
- Basic functionalities provided by nodes to *the network*
  - *'Code' load* – to define services, configuration
  - *Discovery* - detection of nodes, services, resources
  - *Service/Resource Monitoring & Management*
  - *Service composition/coordination*– by third party

- Lightweight architecture: how to provide this with low-capacity nodes?

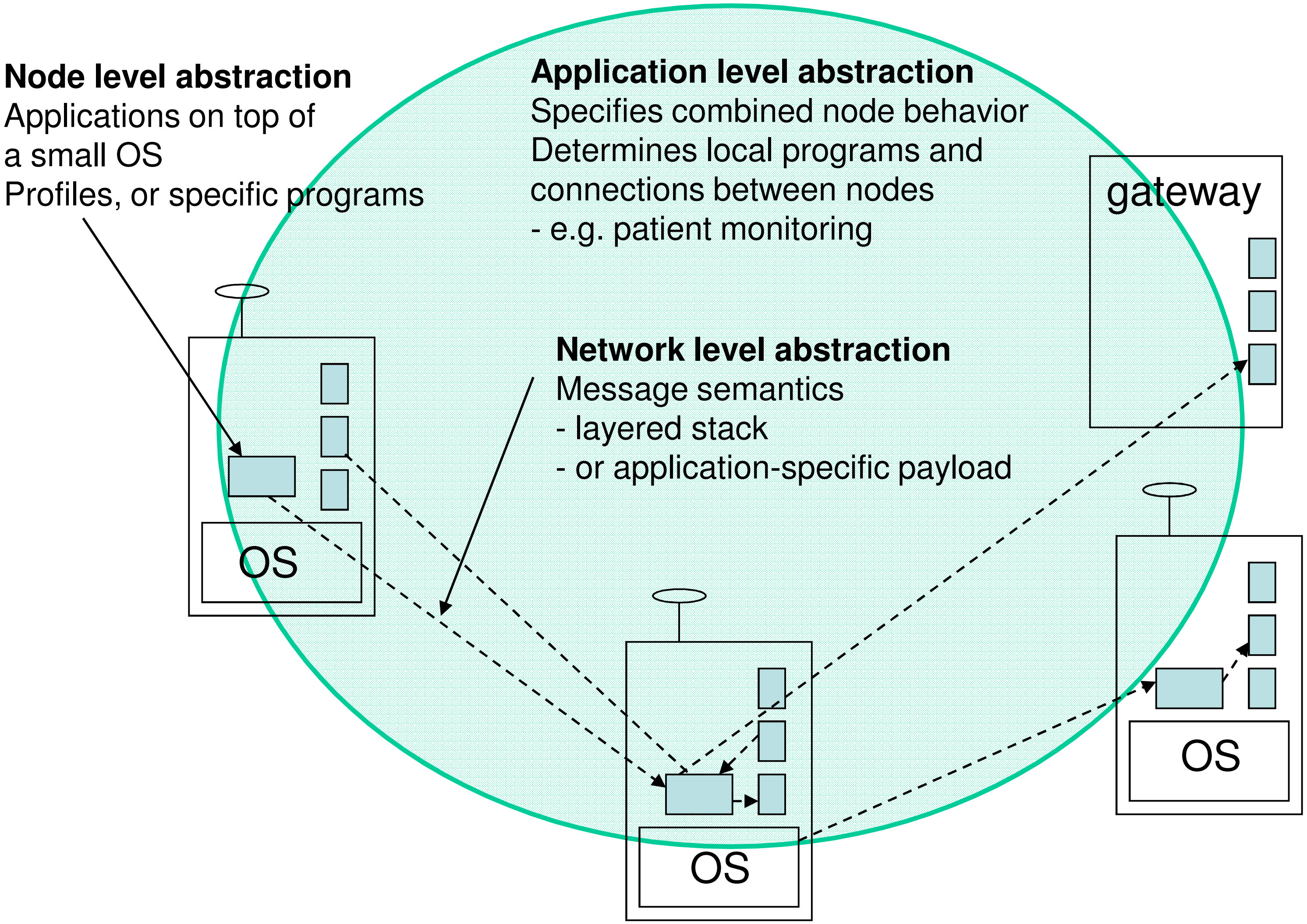
Programming

OK, but how does this work?

- How to use (program) and share the 'terminals' in the space?
  - standardized usage profiles
    - e.g. Zigbee, Bluetooth, perhaps UPnP
      - cannot easily share
      - cannot easily use the distributed compute power
  - centralized access point
    - admits management
      - sharing, access control
    - can form physical gateway
      - leveraging e.g. 6lowpan (IPv6 to all terminals)
    - can add semantics
    - needs at least connectivity management within the low-resource wireless domain (e.g. 802.15.4)
    - latency, complexity, mobility, node diversity



Three levels of abstraction



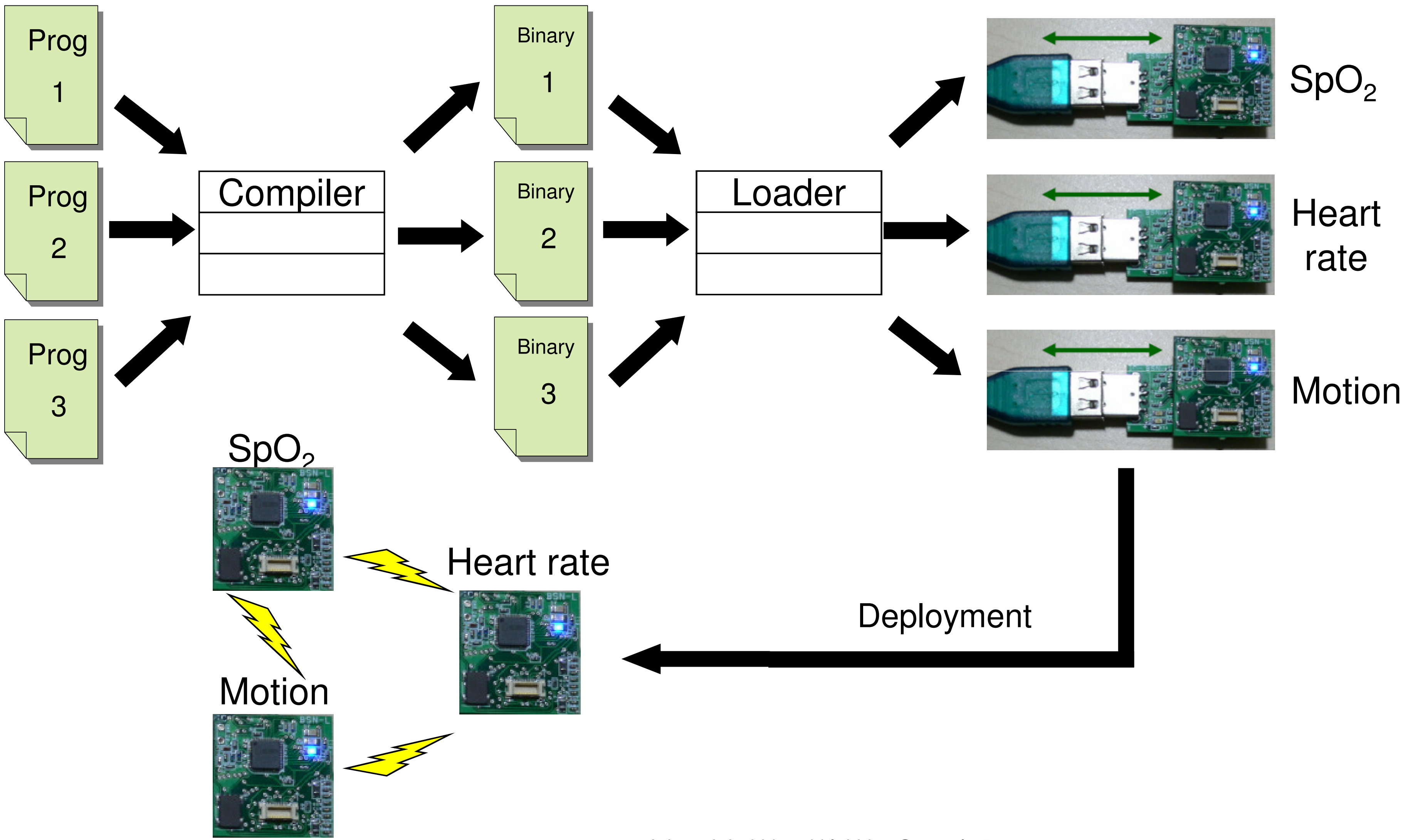
Three levels of abstraction

- Node level: application (part) on node
  - the overall application 'emerges' as the collaboration of these
  - needs good network abstraction for programmers

- Network level: define messages, and semantics
  - supporting layered protocol stack or
    - good for abstraction, bad (?) for performance
  - define the overall application by specifying messages and response to these
    - e.g. along the lines of UPnP

- Application level: focus on overall task, e.g. light scenario
  - leads to construction of local programs (and perhaps messaging) realizing this

‘Traditional’ development applied to sensors



Choices in (re)programming

Code specialization per node

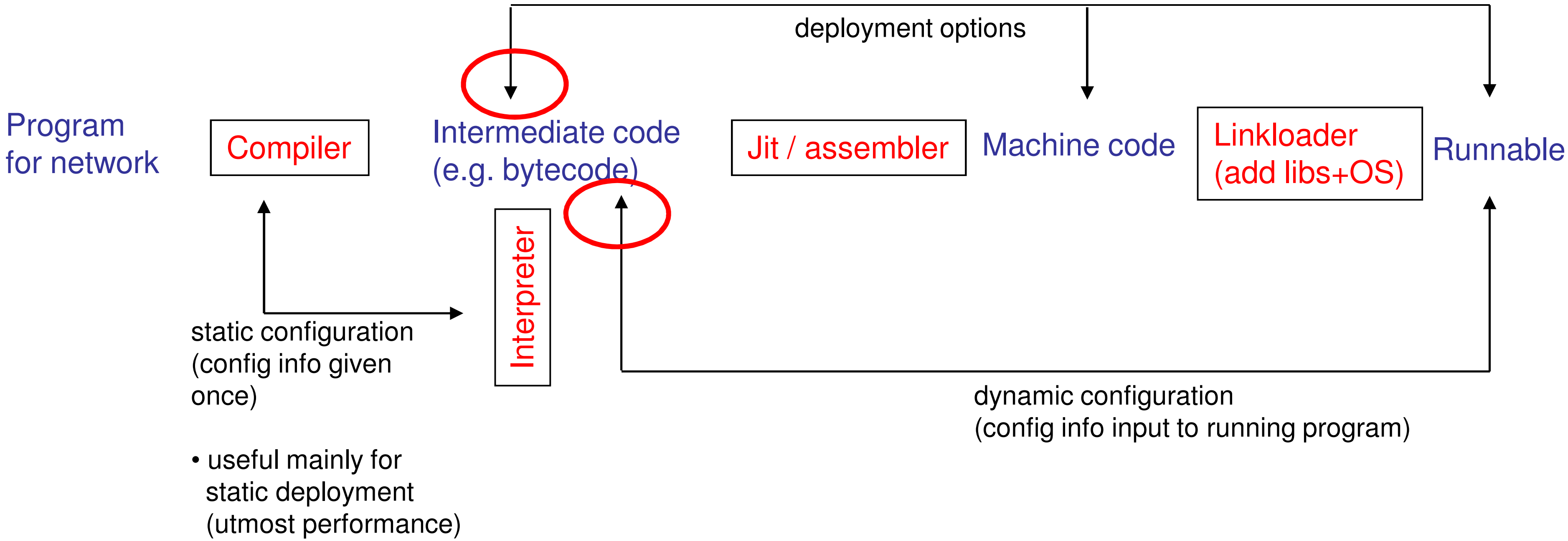
before deployment
• node-specific code
• simpler, for a node

at or after deployment
• all nodes same code
• requires selection mechanism on node

• Compact code
• Machine & OS independence
• Interpreter on nodes
• Good for coordination code

• Compact code (but less)
• Machine & OS dependence
• Linkloader on nodes
• Good for computational code

• Large code
• Machine & OS dependence
• Gives most efficient run-time



Proposed approaches

Some studied approaches

- Virtual machines
  - P. Levis, D. Culler. Maté: a tiny virtual machine for sensor networks, Proc. of ASPLOS-X, 2002.
  - R. Miller, G. Alonso, D. Kossmann, A Virtual Machine For Sensor Networks, Proc. of EuroSys 2007.
- Special-purpose engine
  - S.R. Madden, M.J. Franklin, et al. TinyDB: an acquisitional query processing system for sensor networks, ACM Transactions on Database Systems, Vol.30, Issue 1, March 2005.
  - H. Liu, T. Roeder, et al. Design and Implementation of a Single System Image Operating System for Ad Hoc Networks, Proc. of MobiSys, 2005.
- Macro programming
  - R. Gummadi, O. Gnawali, R. Govindan. Macro-programming Wireless Sensor Networks using Kairos, Proc. of DCOSS, 2005.
  - L. Evers, P.J.M. Havinga, et al. SensorScheme: Supply chain management automation using Wireless Sensor Networks, Proc. of ETFA, 2007.

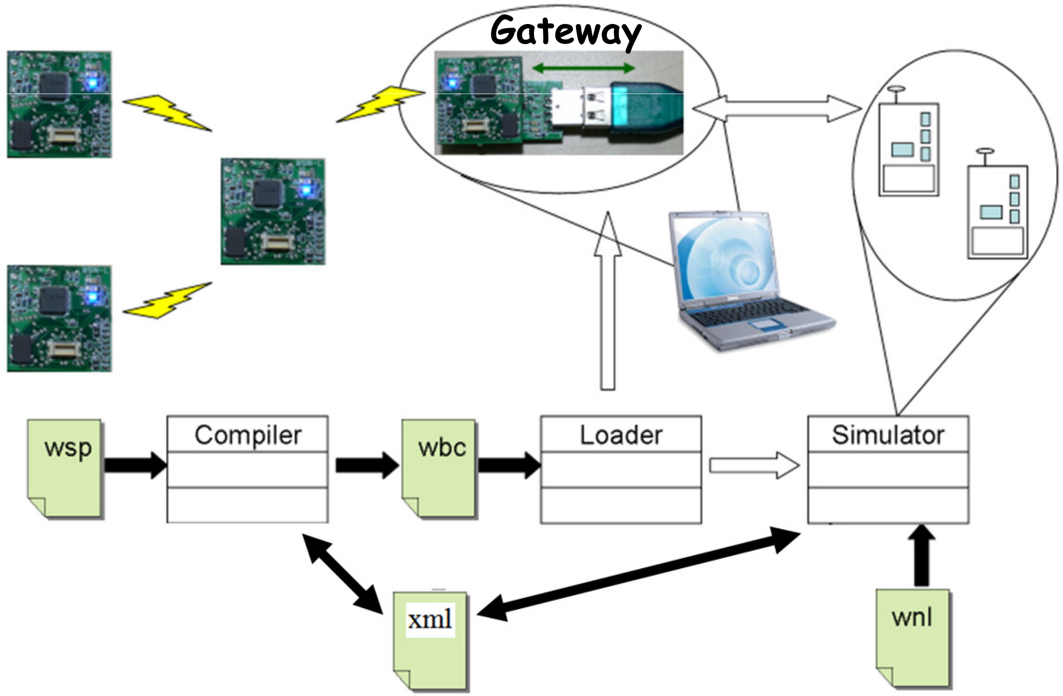
Approaches (cnt'd)

- Active messages
  - P. Levis, D. Gay, and D. Culler, Active Sensor Networks. Proc. of NSDI, 2005.
  - T. von Eicken, D. Culler, et al. Active messages: a mechanism for integrated communication and computation, Proc. of ISCA, 1992.
- IP to the sensors
  - G. Montenegro, N. Kushalnagar, J. Hui, D. Culler, Transmission of IPv6 Packets over IEEE 802.15.4 Networks, RFC4944, 29 pages, September 2007
- Content-based addressing
  - A. Carzaniga, D. S. Rosenblum, and A. L. Wolf. Content-based addressing and routing: A general model and its application. Technical Report CU-CS-902-00, Department of Computer Science, University of Colorado, Jan. 2000.

OSAS @ TU/e

OSAS Framework

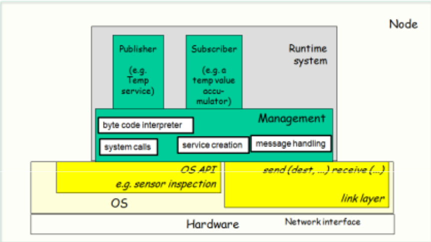
- Open Service Architecture for Sensors (OSAS)
  - *language,* to program the entire network ('macro-programming')
    - with concepts of a service, events and subscription
    - and content-based addressing
  - *virtual machine definition* (byte code ISA)
    - has access to a set of system calls (OS-provided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



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

OSAS Framework: *Programming Model*

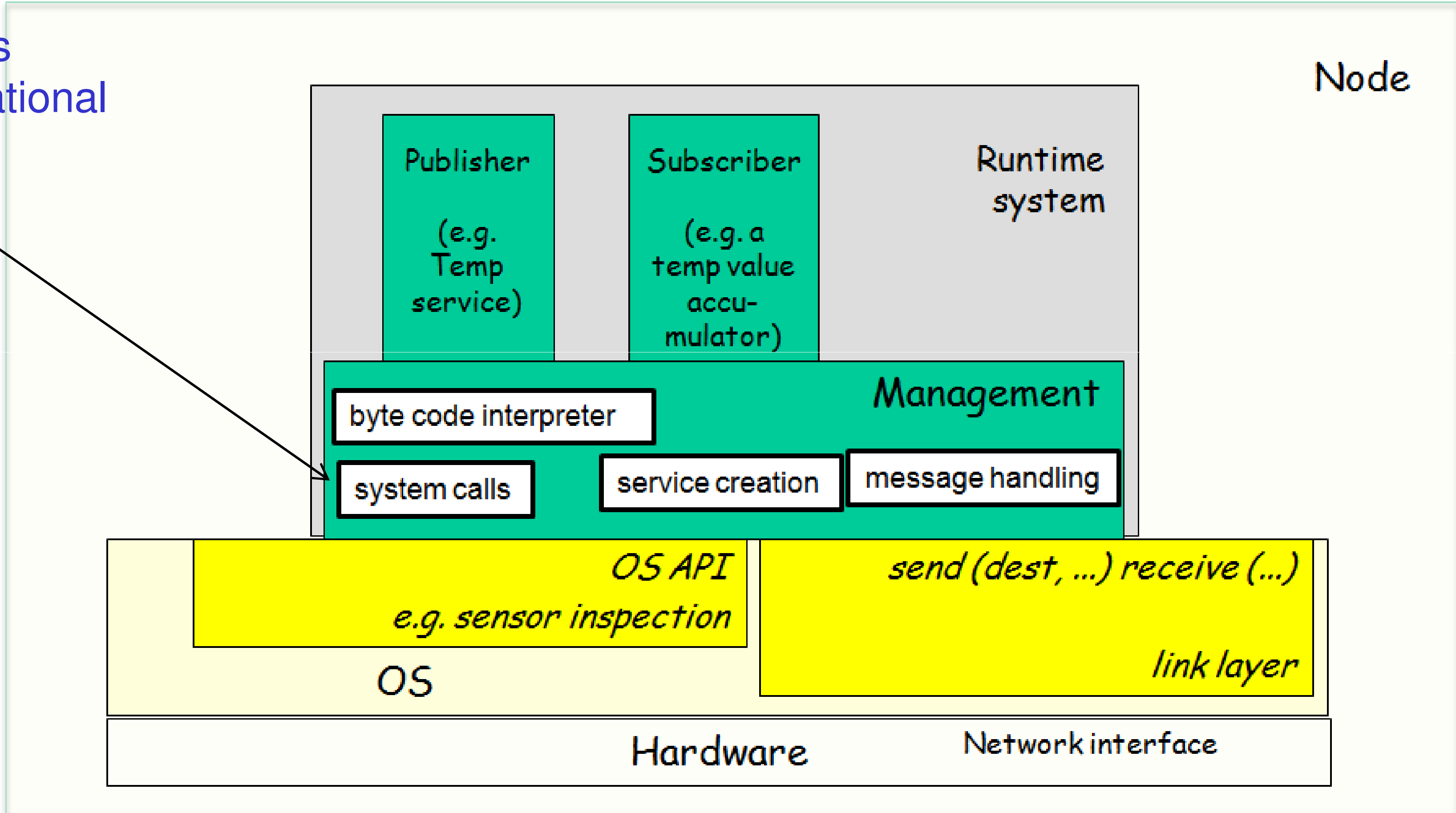
- Nodes run services:
  - A service has event *generators* and event *handlers*.
  - A link between a generator and a handler is called a *subscription*.
  - Interaction between services by a *asynchronous remote procedure call*
    - upon firing of the event
    - or simply as part of a handler

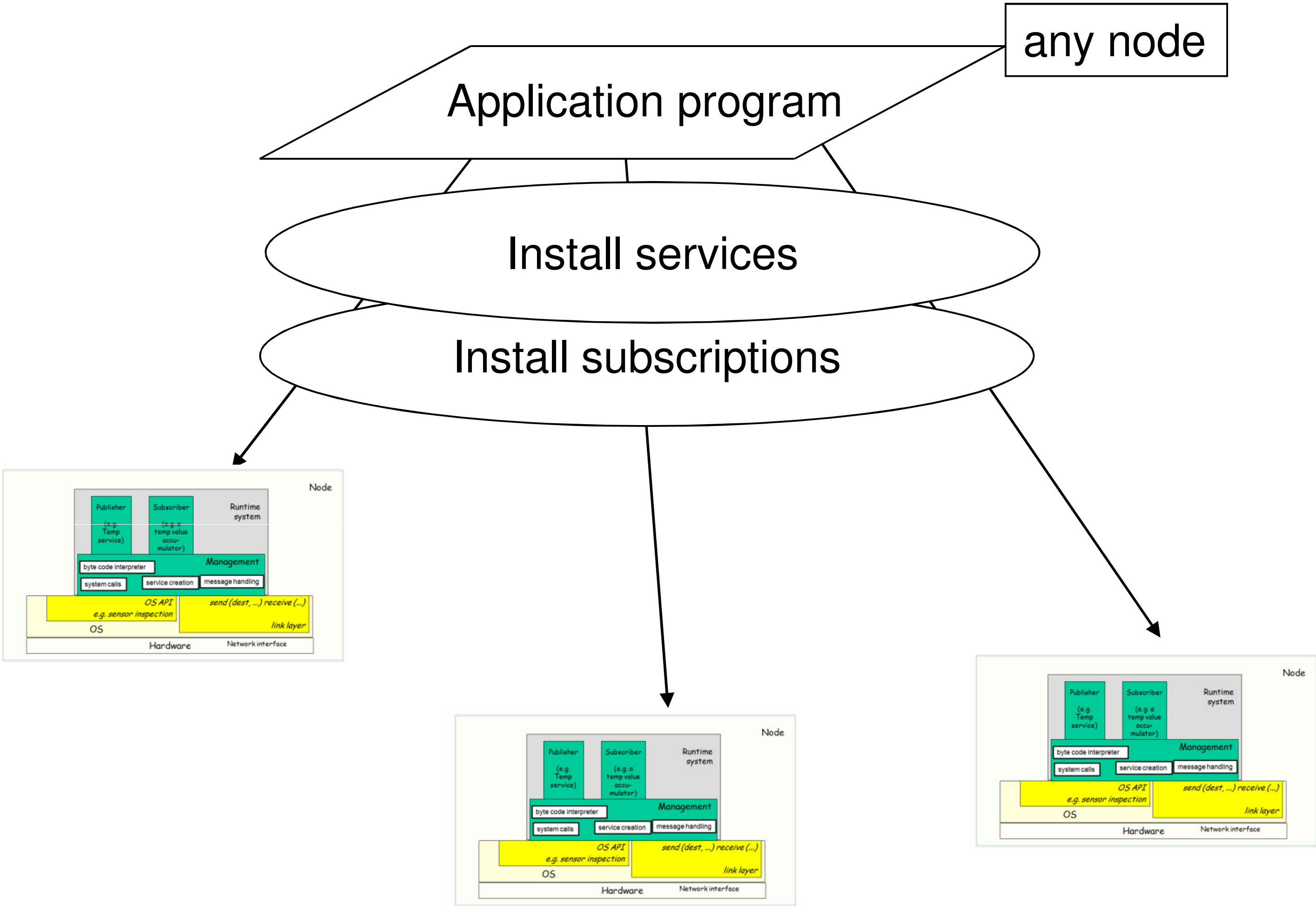


- WASP Service Composition Language (WaSCoL)
  - Specification of services with *event-condition-action* rules
    - condition is evaluated in a time-triggered fashion; when true, fires the action which may call a handler
  - Composition of services (i.e. subscriptions)
  - Use content-based addressing to associate node with service
  - *Programs can be developed and loaded incrementally*

Run-time organization

OS access
+ computational
library





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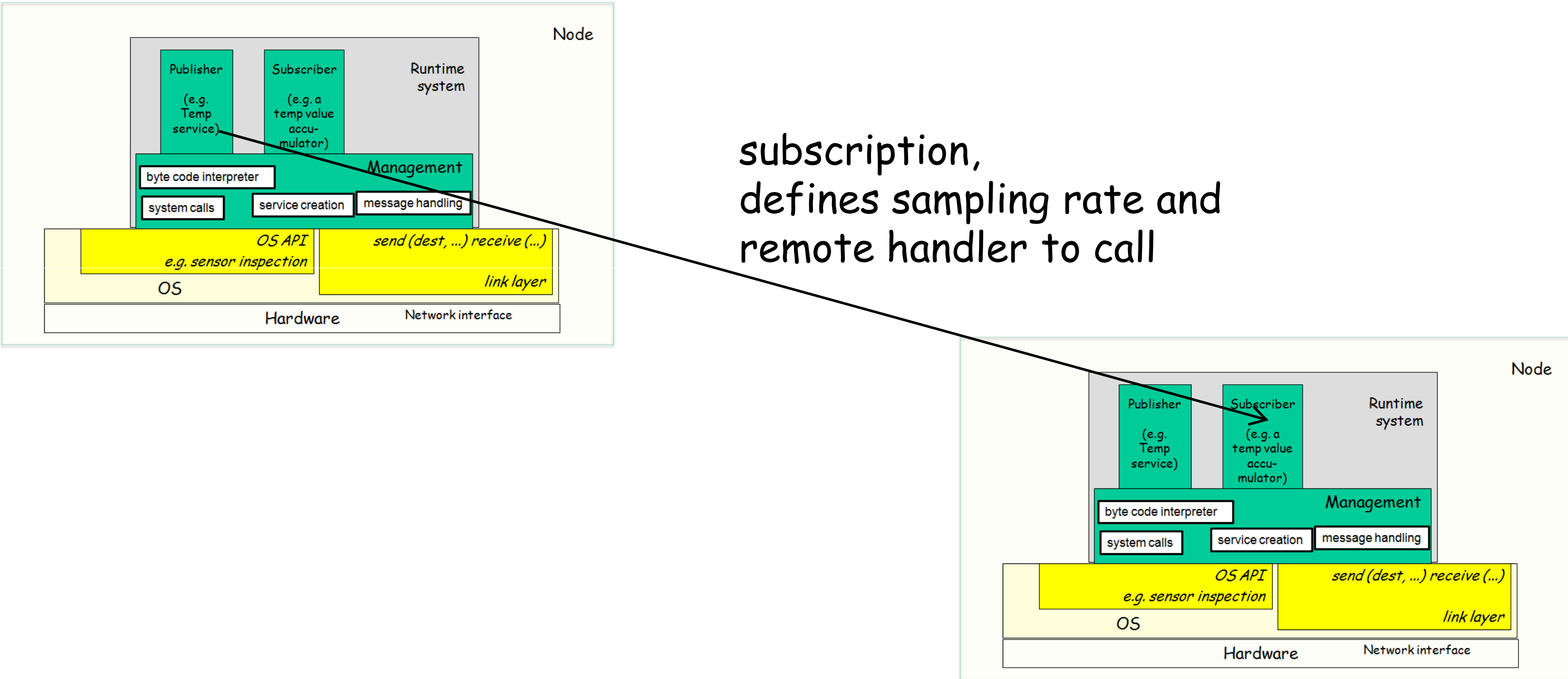
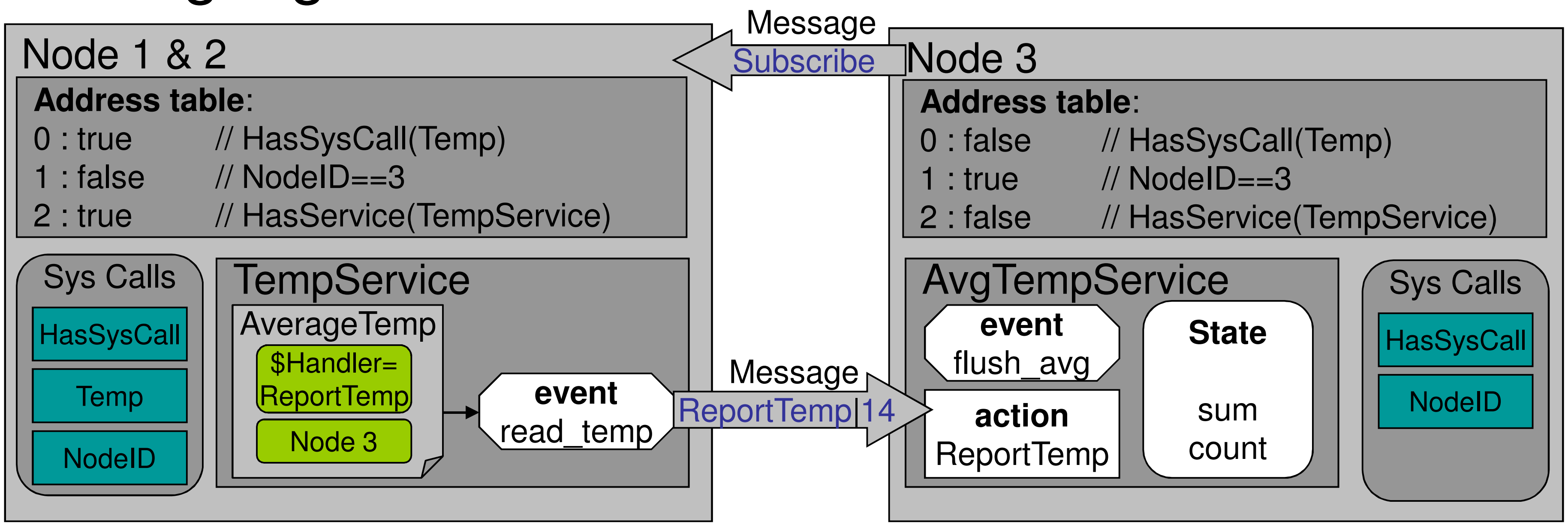
TU/e Informatica, System Architecture and Networking

Connection by subscriptions



Language



service TempService($Handler)
  on event read_temp **when** True **do**
    SendToSubscribers($Handler, Temp())

service AvgTempService($Handler)
  define
    sum := 0
    count := 0
  on event flush_avg **when** 2 <= count **do**
    SendToSubscribers($Handler, sum / count);
    count := 0; sum := 0
  action ReportTemp(temp) **do**
    sum := sum + temp;
    count := count + 1

subscription AverageTemp
to TempService($Handler=ReportTemp)
with (period=30s, deadline=1m,
  send="High", exec="Normal")

for [Network|*|HasSysCall(Temp)]
  install TempService

for [Network|*|NodeID()==3]
  install AvgTempService
  install AverageTemp on
    [Network|*|HasService(TempService)]

Three levels of abstraction: summary

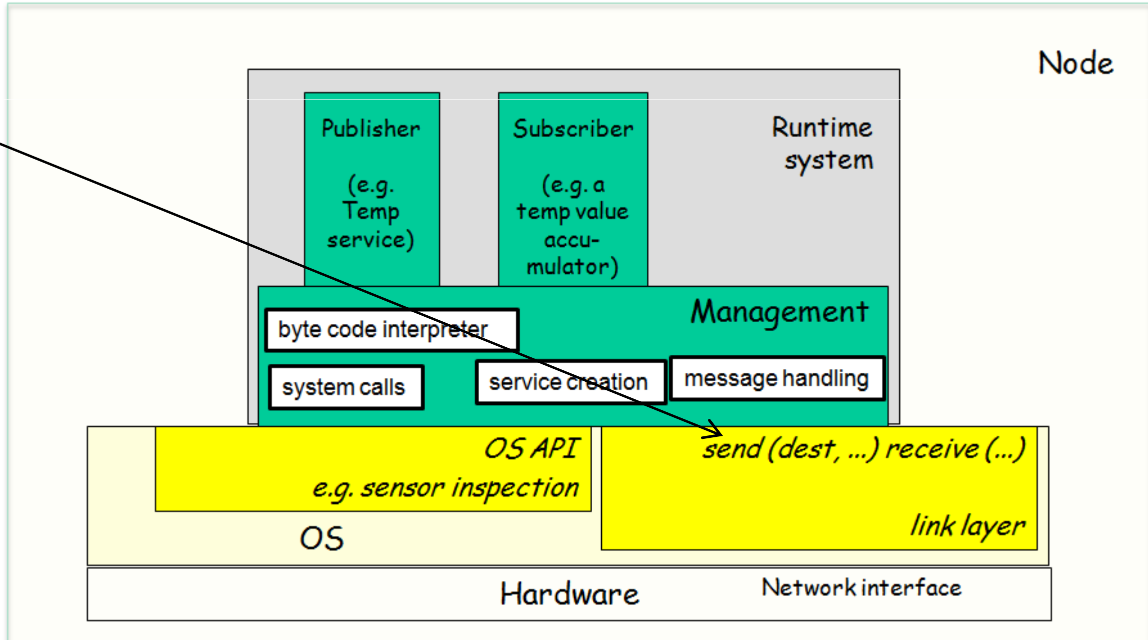
- Node level: application (part) on node
  - a runtime system, with byte code interpreter and service installer
- Network level: define messages, and semantics
  - generic WSP format: [header ; (handler, arguments)]
    - specifies the asynchronous remote procedure call
    - specifics *derived from the program* by the compiler
- Application level: focus on overall task, e.g. light scenario
  - single program for entire network
  - generates collection of service definitions and subscriptions as *separate messages* to be loaded into the network
  - content-based addressing leads to loading the program *just once*
    - nodes use CBA to determine their part

Q & A

- How can this approach limit communication energy?
- How general is this? Does it need standardization?
- What about multi-hop?
- How do two different programs ‘live together’?
- How do I extend an already running system?
- How to discover nodes and services?
- How to connect to IP?

How can this approach limit communication energy?

- Needs: an interface to pass timing information...
  - derived from subscriptions...
  - .... and neighbor information
- ... and a MAC protocol that uses this
  - e.g. WISEMAC, TRAWMAC



How general is this? Does it need standardization?

- The messaging assumes a *link;* it can be bound to any link
  - a LLC/MAC protocol
  - a 6lowpan transport overlay
  - a general IP overlay
  - Zigbee messaging

What about multi-hop?

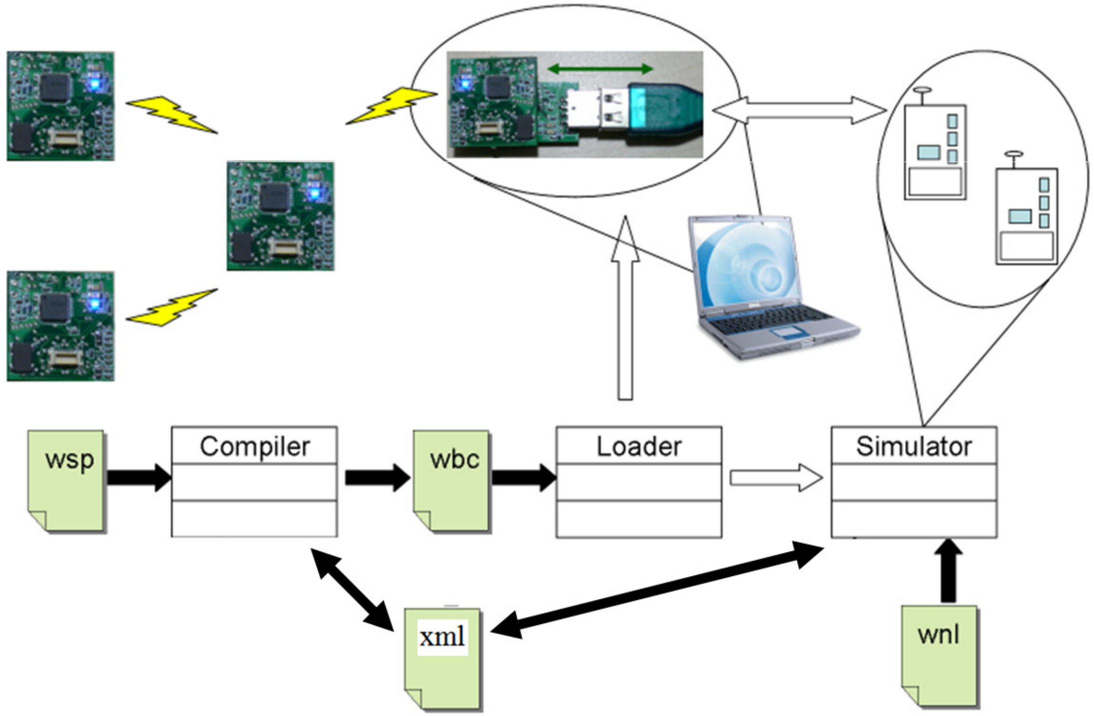
- A subscription defines a source-destination route
  - mobility means: re-subscribing
- The language definition is powerful enough to specify general routing
- We have used it to implement a few common routing protocols
  - gradient routing
  - path reconstruction (mobility)
  - shortest paths spanning tree
  - source routing

How do two different programs 'live together'?

- Message headers contain an 'application id'
- Service *s* can now be addressed using (*app_id, s*)

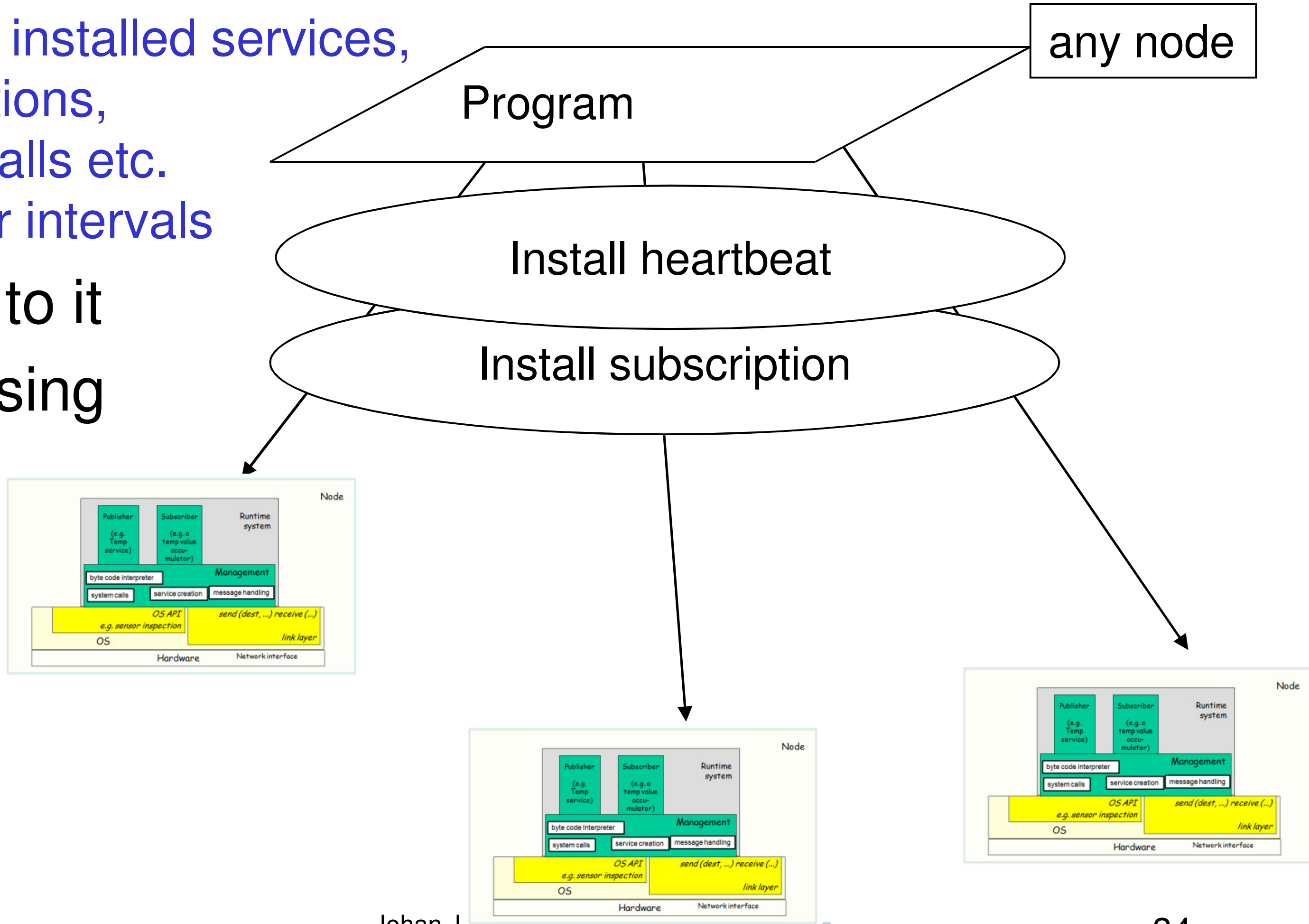
How do I extend an already running system?

- The xml-file is:
  - *output* of the compiler – describes system symbols, their meaning and their mapping to integers
  - *input* to the compiler: as a description of the running system

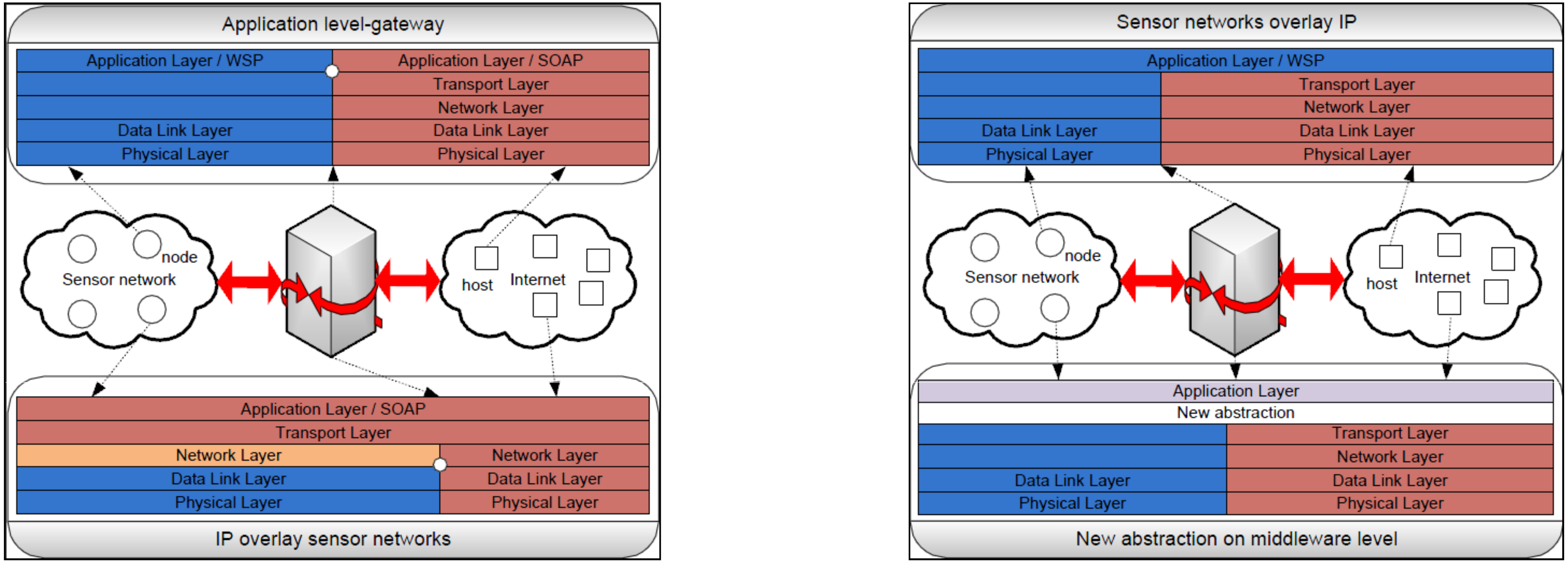


How to discover nodes and services?

- Inject a small heartbeat service, for all nodes
  - reporting installed services, subscriptions, system calls etc. at regular intervals
- Subscribe to it
- Interpret using the xml output of the compiler



How to connect to IP?

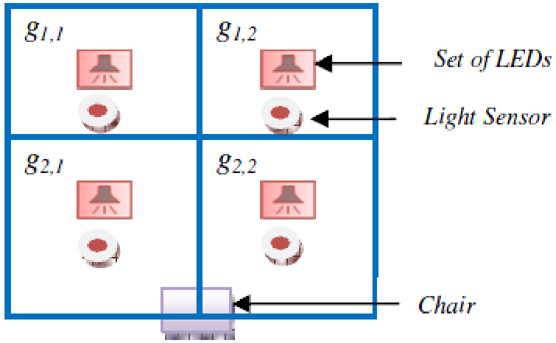


- Application-level gateway: translation, including semantics
- IP overlay sensor networks: e.g. 6lowpan
  - can connect transparently to sensors – may lead to 'expensive' protocols (SOAP)
- sensor networks overlay IP
  - nodes are simulated on IP; there, powerful system calls are provided

Concluding

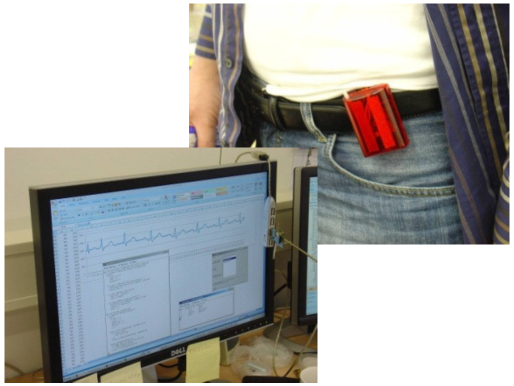
Was it useful?

- Light control system
  - actively controlling light intensity according to user preference (coming from new device in the space)



Sachin Bhardwaj, Tanir Ozcelebi, Johan Lukkien, *Smart Lighting Using LED Luminaries*, IEEE PerCom SmartE 2010.

- On-node ECG processing
  - determine timed heart beats
  - combine with accelerometer to have better diagnosis

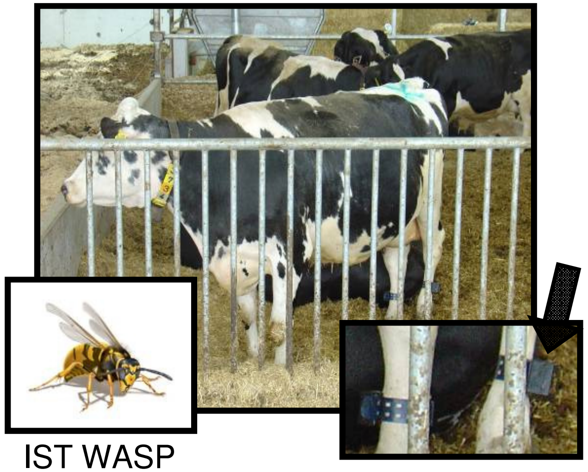


Diana Albu, Richard Verhoeven, Johan Lukkien, *On-node processing of ECG signals,* IEEE CCNC, January 2010.

- Connect a light to the heartbeats ☺

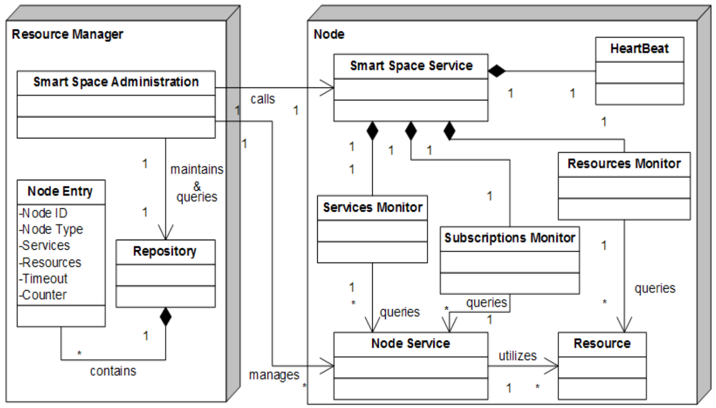
Was it useful?

- Herd monitoring in the WASP project
  - use observations to adjust subscriptions
    - e.g. animal moving -> step detection
  - full in-network processing
  - full over-the-air programming
  - context dependence:
    - inside barn: all nodes reachable
    - outside: use routing



IST WASP

- Smart space resource management architecture



Conclusion

- An integral approach to programming wireless sensor networks
  - *node, network, application* level
  - limit errors, fast program construction and deployment
  - over-the-air programming, with *single image*
  - in fact, more general than just sensor networks
- Concepts of *services, events, subscriptions, content-based addressing*
- Admits mapping onto existing systems
- Addresses requirements of smart spaces
  - also: flexibility and agility

Ongoing work

- Improve security, access control, privacy

- Examine more applications
  - lighting, in-network processing
  - experiment with keeping generated information internal, and use in control decisions

- Complete an energy-efficient MAC