Reconceptualizing a Family of Heterogeneous Embedded Systems via Explicit Architectural Support

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Outline

- Wireless Sensor Networks
- WSN Middleware
- Cluster-Based Middleware
- MIDAS Application
- Middleware in MIDAS
- Conclusions

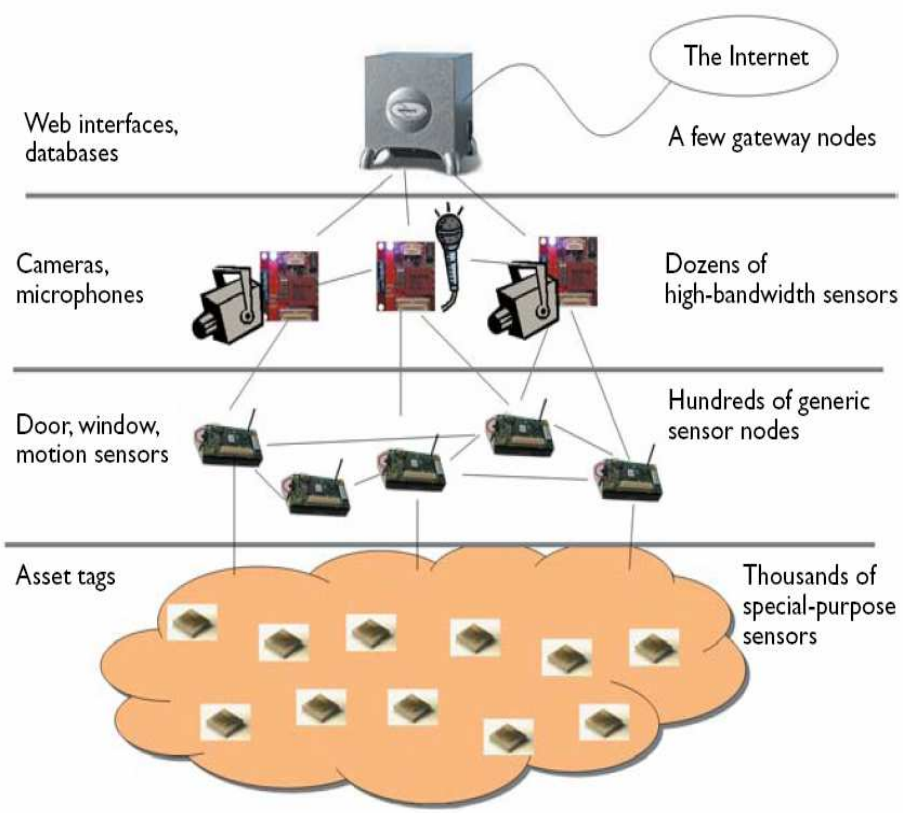
Wireless Sensor Networks

- Pervasive
  - Medicine
  - Defense
  - Security
  - Navigation
  - Automation
  - And many others

Wireless Sensor Networks (2)

- Combining sensing, processing and communications into tiny embedded devices
- Devices of different scales and resources
  - Possibly mobile, unattended operation
- New OSs (TinyOS) and appropriate PLs (nesC)

Wireless Sensor Networks (3)



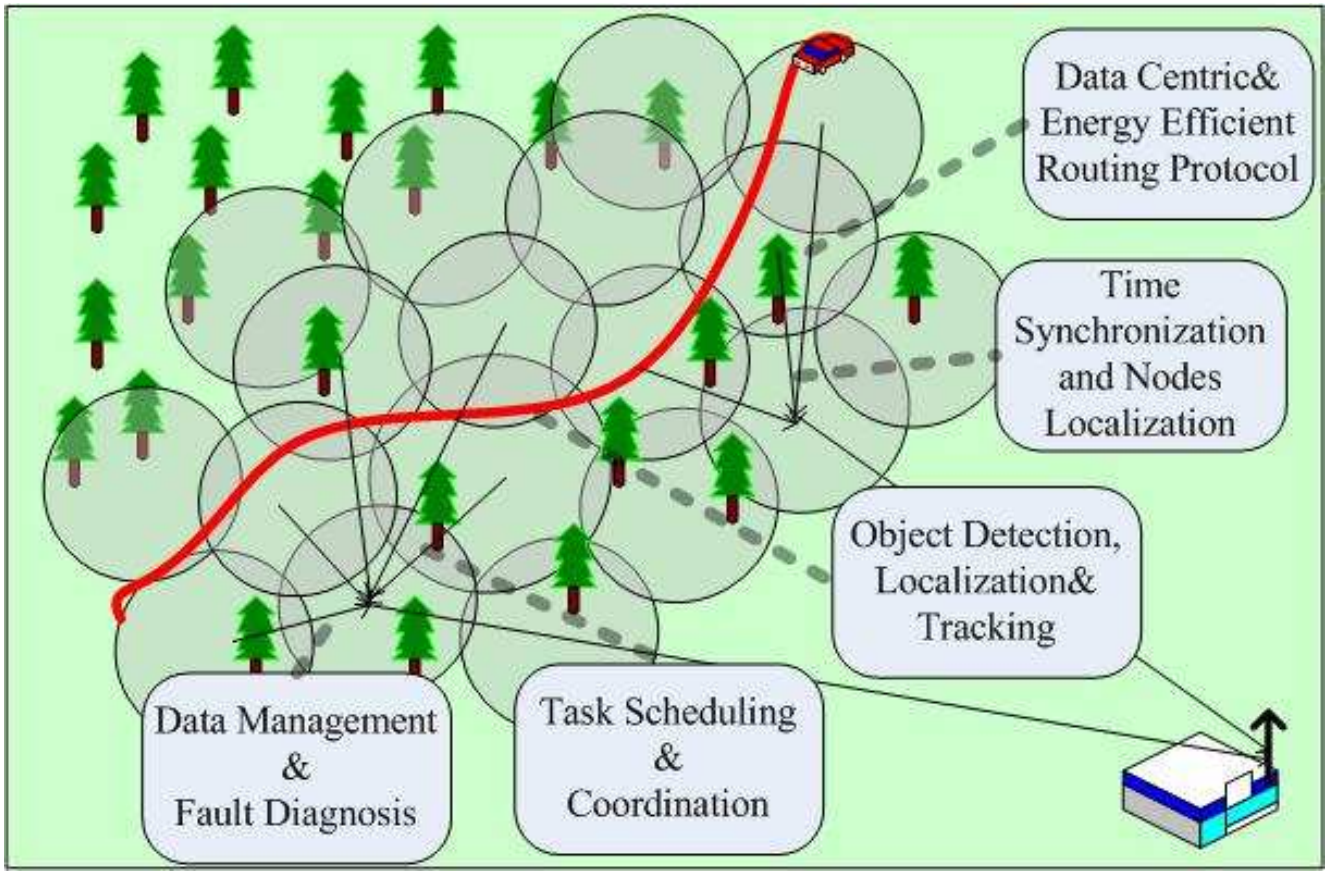
Node Type	Sample "Name" and Size	Typical Application Sensors	Radio Bandwidth (Kbps)	MIPS Flash RAM	Typical Active Energy (mW)	Typical Sleep Energy (uW)	Typical Duty Cycle (%)
Specialized sensing platform	Spec mm^3	Specialized low-bandwidth sensor or advanced RF tag	<50Kbps	<5 <0.1Mb <4Kb	1.8V*10–15mA	1.8V *1uA	0.1–0.5%
Generic sensing platform	Mote 1-10cm^3	General-purpose sensing and communications relay	<100Kbps	<10 <0.5Mb <10Kb	3V*10–15mA	3V *10uA	1–2%
High-bandwidth sensing	Imote 1-10cm^3	High-bandwidth sensing (video, acoustic, and vibration)	~500Kbps	<50 <10Mb <128Kb	3V*60mA	3V *100uA	5–10%
Gateway	Stargate >10cm^3	High-bandwidth sensing and communications aggregation Gateway node	>500Kbs–10 Mbps	<100 <32Mb <512Kb	3V*200mA	3V *10mA	>50%

Wireless Sensor Network Middleware

- Dynamic environment
  - Node mobility
  - Node failures
  - Environmental obstructions
- Often even without a notion of OS

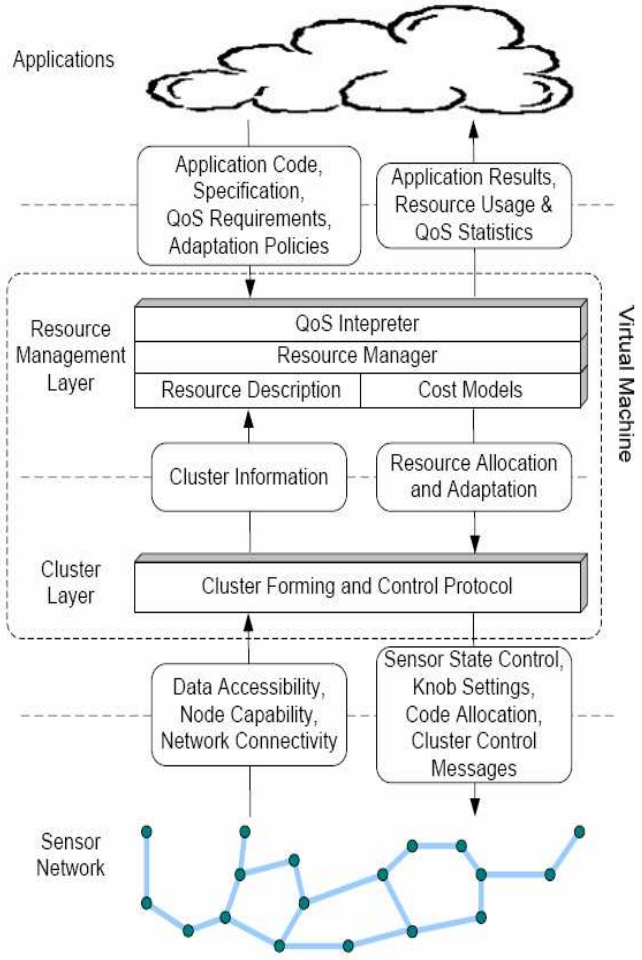
Wireless Sensor Network Middleware (2)

- Purpose
  - Development
  - Maintenance
  - Deployment
  - Execution
- Middleware for sensor networks should provide holistic view on both WSN and traditional networks, which is a challenge for architectural design and implementation [2]


Data Centric&
Energy Efficient
Routing Protocol
Time
Synchronization
and Nodes
Localization
Object Detection,
Localization&
Tracking
Data Management
&
Fault Diagnosis
Task Scheduling
&
Coordination

Cluster-Based Middleware Architecture

- Spatially close sensors form clusters
  - Perform tasks through coordination
  - One node is a cluster head



Problem

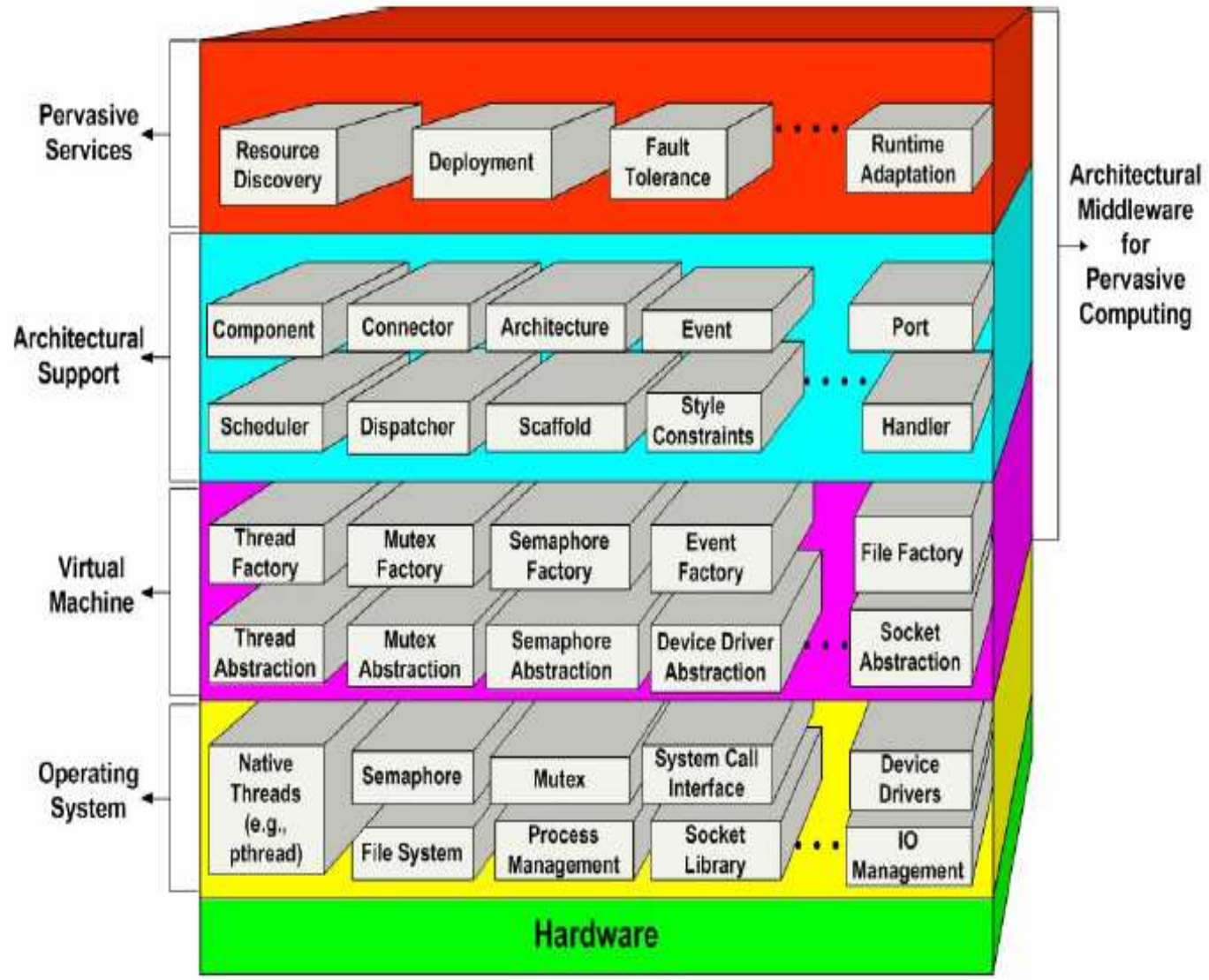
- MIDAS

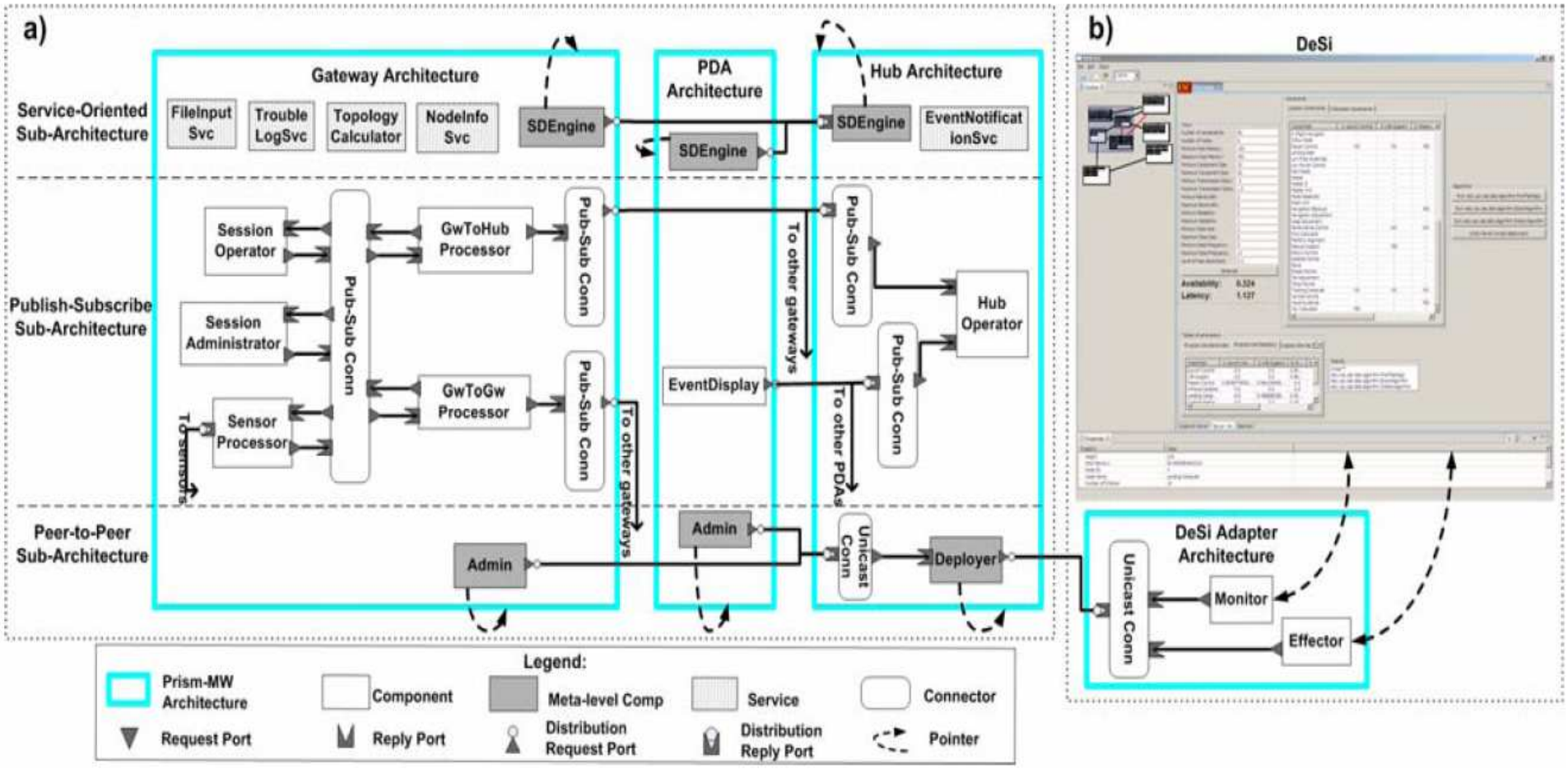
Requirements

- Resource consumption
- Performance
- Scalability
- Heterogeneity
- Fault-tolerance
- System modeling and analysis
- Deployment
- Service discovery
- Monitoring
- Architecture-based development
- Multiple architectural styles

Middleware Architecture

- Layered system stack
  - Modular Virtual Machine (MVM)
    - Unintended dependencies
    - Lack of support for service discovery, dynamic adaptation, component-level deployment
  - Prism-MW
    - Prism-MW in Java, embedded systems in C/C++
  - DeSi


Pervasive Services
Resource Discovery
Deployment
Fault Tolerance
Runtime Adaptation
Architectural Middleware for Pervasive Computing
Architectural Support
Component
Connector
Architecture
Event
Port
Scheduler
Dispatcher
Scaffold
Style Constraints
Handler
Virtual Machine
Thread Factory
Mutex Factory
Semaphore Factory
Event Factory
File Factory
Thread Abstraction
Mutex Abstraction
Semaphore Abstraction
Device Driver Abstraction
Socket Abstraction
Operating System
Native Threads (e.g., pthread)
Semaphore
Mutex
System Call Interface
Device Drivers
File System
Process Management
Socket Library
IO Management
Hardware


a)
Gateway Architecture
PDA Architecture
Hub Architecture
Service-Oriented Sub-Architecture
FileInput Svc
Trouble LogSvc
Topology Calculator
NodeInfo Svc
SDEngine
SDEngine
SDEngine
EventNotificationSvc
Publish-Subscribe Sub-Architecture
Session Operator
Session Administrator
Sensor Processor
To sensors
Pub-Sub Conn
GwToHub Processor
GwToGw Processor
Pub-Sub Conn
Pub-Sub Conn
To other gateways
Pub-Sub Conn
Hub Operator
EventDisplay
Pub-Sub Conn
To other PDAs
To other gateways
Peer-to-Peer Sub-Architecture
Admin
Admin
Unicast Conn
Deployer
b)
DeSi
DeSi Adapter Architecture
Unicast Conn
Monitor
Effector
Legend:
Prism-MW Architecture
Component
Meta-level Comp
Service
Connector
Request Port
Reply Port
Distribution Request Port
Distribution Reply Port
Pointer

Satisfying the Requirements

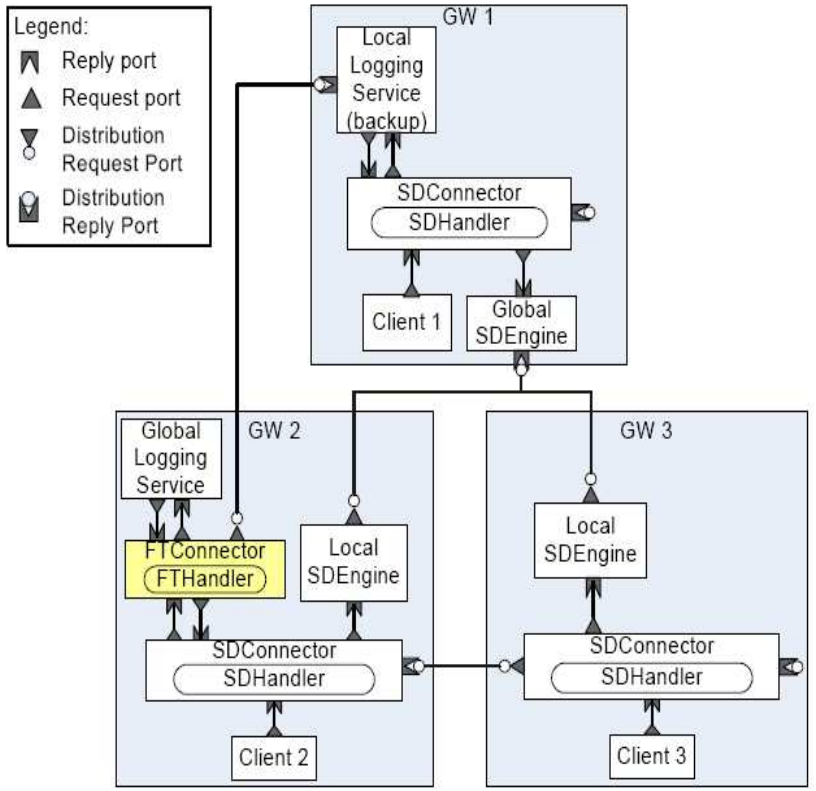
- Resource consumption
  - Object pre-allocation
  - MVM factory facilities
- Performance
  - Priority dispatcher and scheduler
- Scalability
  - Reducing configurations to minimal facilities

Satisfying the Requirements (2)

- Heterogeneity
  - Hardware platforms
  - Operating systems
  - Programming languages
    - *AbstractConversion* implementation

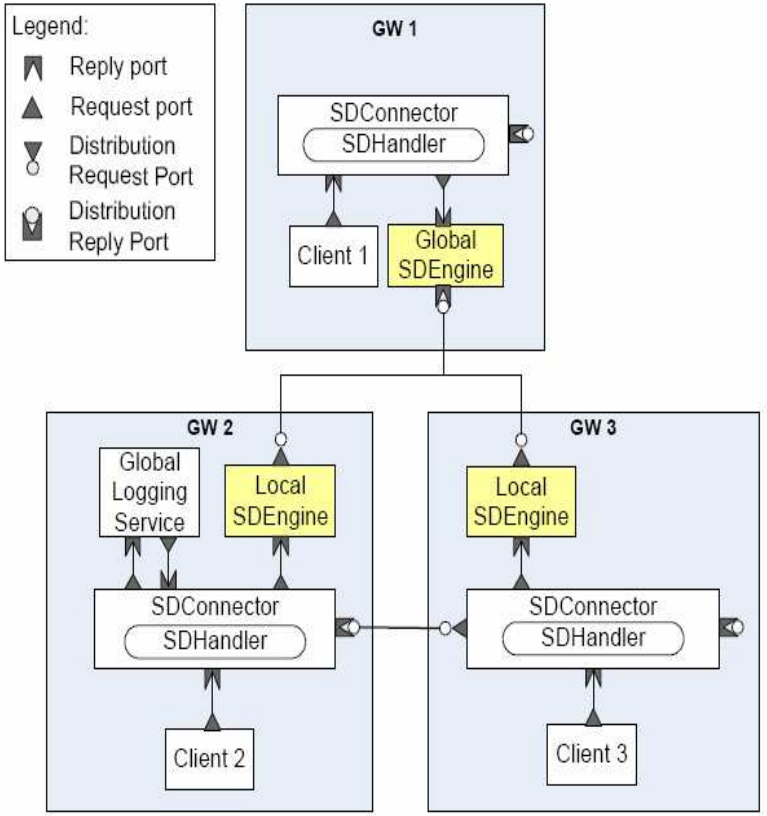
Fault-Tolerance in MIDAS

- Active replication
  - *BestEffortFTConnector*
  - *RealTimeFTConnector*



Service Discovery in MIDAS

- Location transparency by using *SDEngine*



Tradeoffs

- Ease of use vs. configurability
- Academia
  - General solutions applicable in more cases
- Industry
  - Particular problems, lower level solutions

Paper Review

- Good sides
  - Nice insight into problems when dealing with embedded systems through real-world WSN application experience
- Bad sides
  - Can Prism-MW really be used in general WSNs
    - How small can the sensor nodes be
    - Support for sensor nodes clustering
    - Dynamic formation of ad-hoc networks
  - No information about related work in WSN middleware

References

[1] S.Malek, C. Seo, S. Ravula, B. Petrus, N. Medvidovic: Reconceptualizing a Family of Heterogeneous Embedded Systems via Explicit Architectural Support. In Proceedings of ICSE 2007, Minneapolis, May 2007.

[2] C. Seo, S. Malek, G. Edwards, D. Popescu, N. Medvidovic, B. Petrus, S. Ravula: Exploring the Role of Software Architecture in Dynamic Fault Tolerant Pervasive Systems. In Proceedings of SEPCASE 2007, Minneapolis, May 2007.

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[5] Y. Yu, B. Krishnamachari, V. Prasanna: Issues in Designing Middleware for Wireless Sensor Networks. IEEE Networks, Vol. 18 (1), 2004.

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