Autonomic Sensing Infrastructure

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SRC/SFI/NSF Forum on Integrated Sensors for Cybersystems

WSN Middleware Grand Challenges

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- **Autonomy and Adaptivity**
  - Providing systems that adapt autonomously to change
  - Providing predictable behaviour in uncertain environments

- **System Challenges**
  - **Prolonging Network Longevity:** Reducing the cost of *dynamically tasking* the network.
  - **Enabling Multiple Applications/Users:** Providing a mechanism by which to multiplex multiple application overlays upon the same sensor network.
  - **Distribution of Data:** multiply located databases, provenance of semi-structured data; dynamically locating and moving data within network.
  - **Autonomy:** distributed reasoning as a strategy for system adaptation.
  - **Balancing Reliability with Cost:** Probabilistic modeling: quantifying uncertainty, evaluating performance over potentially continuous heterogeneous data streams.
  - **Boundaries, resources and trust:** The discipline of access to resources (including space, time, hardware and services) and the criteria for authourising such access.

Toward Autonomic Middleware

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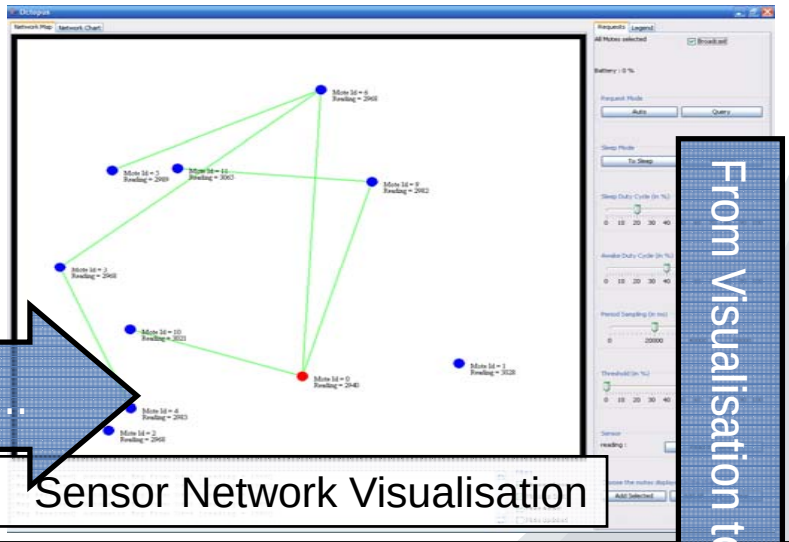
Shrink Wrapped Middleware Agents

Framework	Distribution Jar Size	NCSS	Cyclomatic Co
AFME	84k	2601	
3APL-M	196k	3047	
JADE-LEAP	627k	12080	
MicroFIPA-OS	1268k	21847	.54
CougaarME	169k	5330	2.3
Agilla	No Jar file	4721	.97

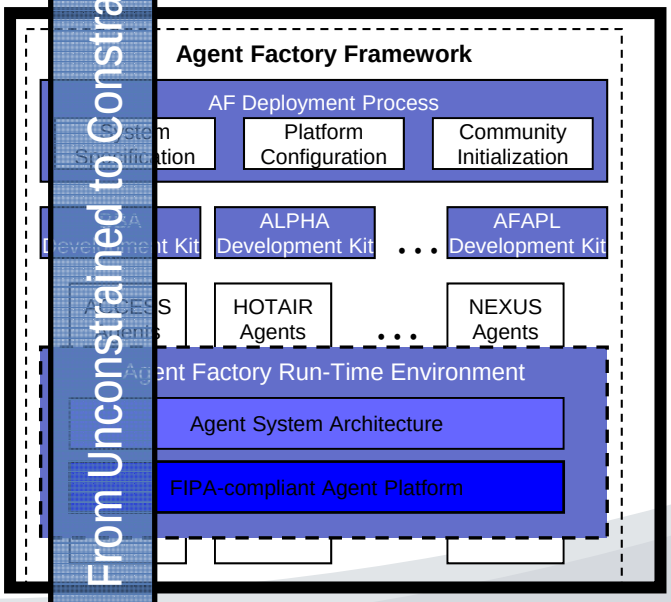
From Miniaturisation to Simulation…



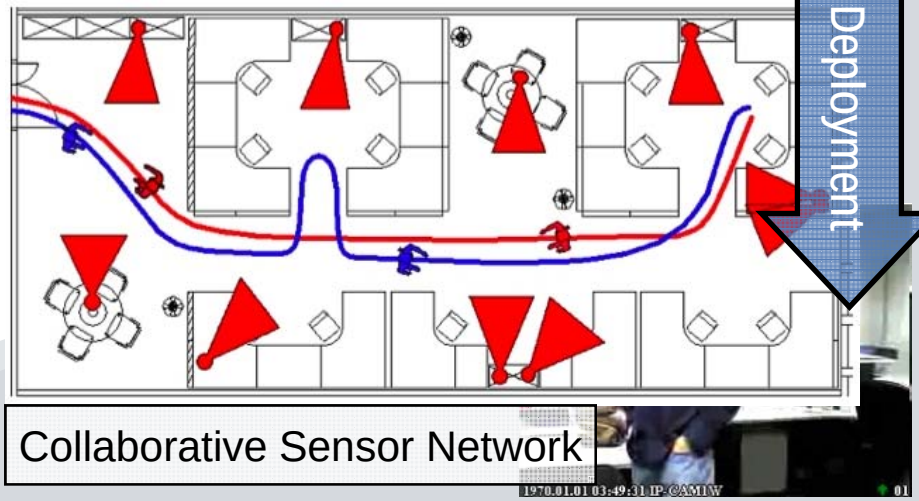
Sensor Network Visualisation

From Visualisation to Deployment

From Unconstrained to Constrained



Intelligent Infrastructure



Collaborative Sensor Network

Sensing Intelligently is Very Difficult

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- Very often we think of sensing as a relatively straightforward process of data capture given an appropriate sensing infrastructure.
- However, this blind gathering of data is an overly simplistic view, which naively fails to consider the use to which the data will be put, and the power envelope within which it must be assembled.
- The manner in which data is gathered should be influenced by the ongoing use of that data in a variety of application and user contexts.
- In practice, this means that not only should research provide mechanisms for harmonising, synchronising, representing and filtering data but it should also be moderated based upon feedback resulting from its very usage.

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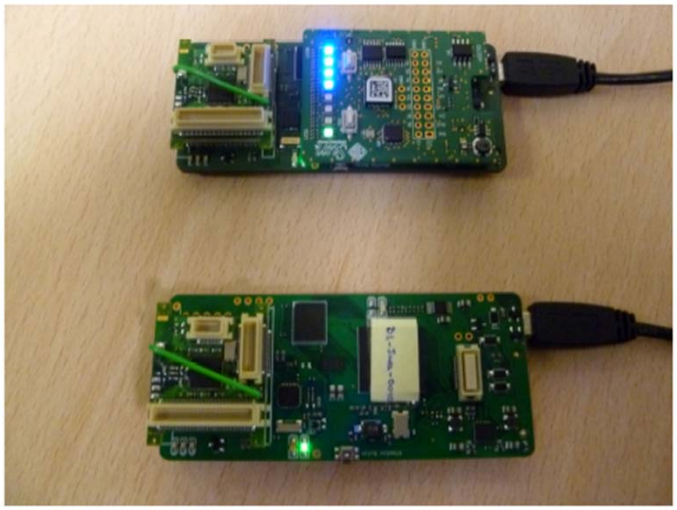
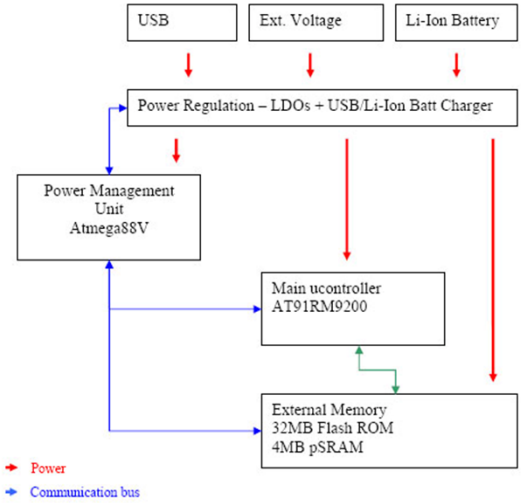
CLARITY WSN Testbed

CLARITY iWSN Java-based Sensor Platform





- A Java Enabled Sensor Platform based on ARM Processor
- Accommodates and integrates a Power Probe which will enable experimentation and validation of energy aware reasoning;
- Hosts and Integrates Middleware on Sensor Platform;

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SIXTH: Enabling Autonomic Sensing

Dimensions of Hetrogeneuity

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Operating System Level: TinyOS, Contiki

Programming Language Level: C, NesC, Java

VM Level: SQUAWK, Mate, Agilla, AFME

Group Level: Hood, Abstract Regions

Abstractions: TinyDB, AToM

Reprogramming: Deluge

SIXTH Overview

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SIXTH's goal is:

"an extensible, scalable, intelligent middleware for WSN based on OGSi"

SIXTH Philosophy:

SIXTH is targeted at dynamic and adaptive WSN's and is focused on runtime re tasking of sensors and in-situ intelligence

SIXTH Components:

Sensor Model: Properties-based model for control of and access to sensing devices.
Adaptors: Links sensor specific implementations to a standardised interface that can be accessed via higher-level APIs.
APIs: Core functionality of the SIXTH architecture, covering: data access, re-tasking, notification, security and discovery.
Services: Data processing layers that build on the APIs.
Intelligence: Integrated multi-agent system to support in-situ reasoning and management.

Key Features

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Common Sensor Architecture :

SIXTH forces a properties-based model on all sensor platforms

Sensing and re-tasking of WSNs :

Cyber Sensors: SIXTH supports dynamically configured data streams that can be both public and personalised (RSS, Twitter, Gowalla, Facebook, …)

Physical Sensors: SIXTH supports dynamically adapting physical WSN's (runtime adaptation of the sensor network is catered for and in fact expected)

Data Processing through Services & Abstract Sensors :

Abstract Sensors act as data aggregators

Services selectively process and dispatch (abstract) sensor data

In-situ intelligence :

Embedded agents use local knowledge to autonomously adapt the WSN properties to meet changing requirements

SIXTH Demonstration

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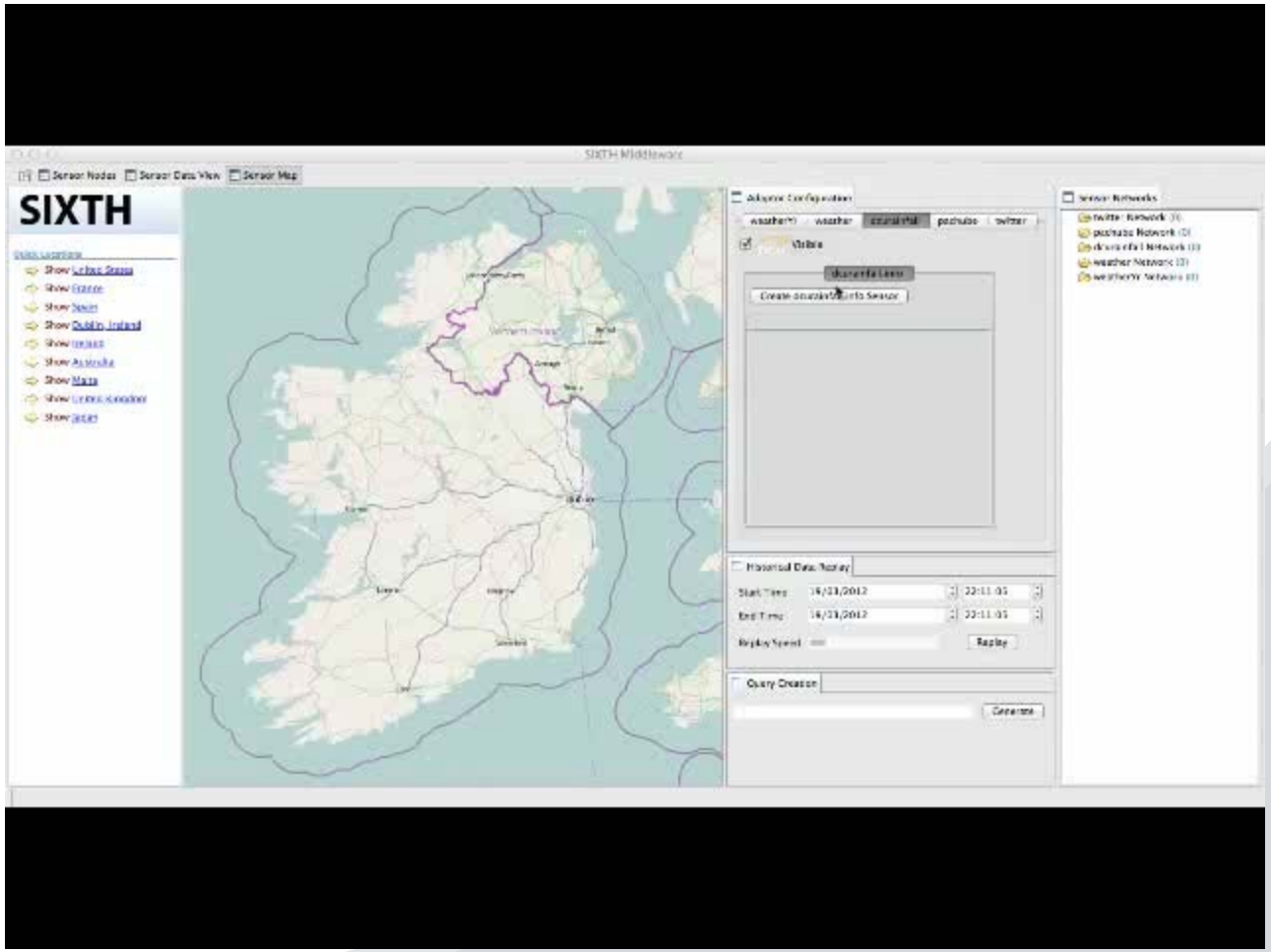
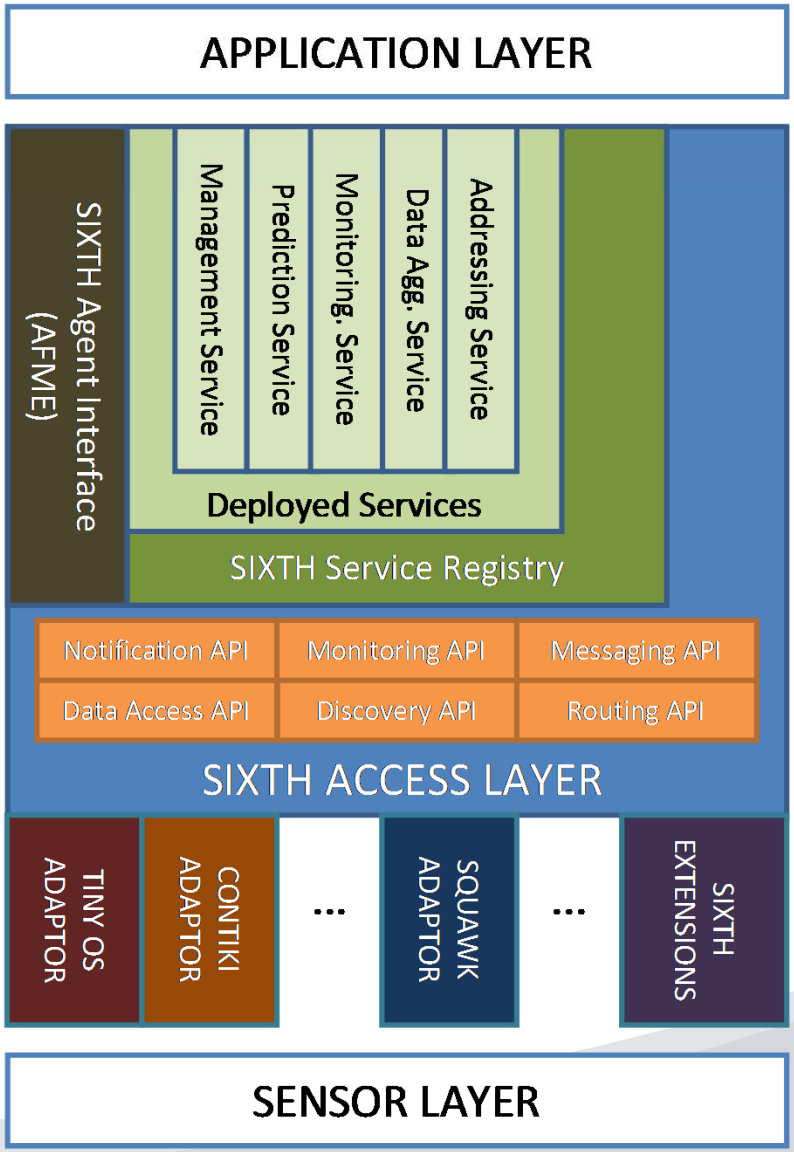


www.clarity-centre.org/SIXTH/

SIXTH Overview

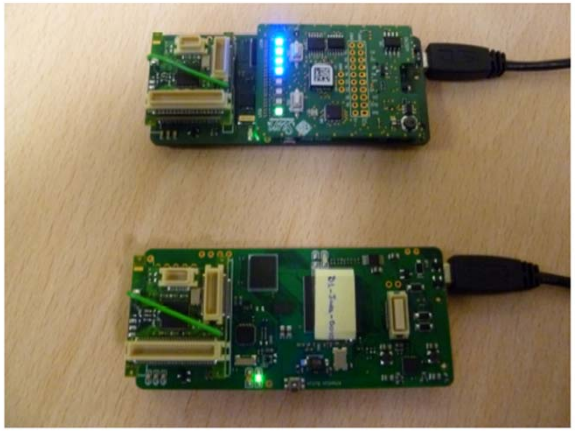


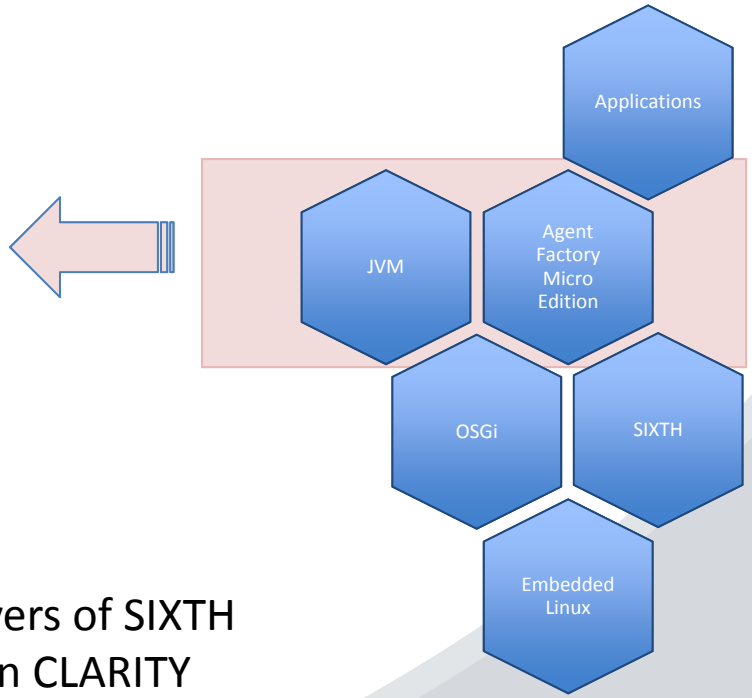
Features:

1. Modularity – components can be reconfigured at run-time and possibly automatically
2. Flexibility – components can be added and removed at run-time and possibly automatically
3. Reusability – components must be reusable
4. Open – use open standards for interoperability
5. Extendible – allow other users to hook into our work
6. Universal - exists in some form on all nodes
7. Hides complexity
8. Treat equals equally and unequals unequally – don't constrain resources

Level	Requirements
BASIC (1)	Data Access / Discovery / Routing
EXTENDED (2)	Messaging / Monitoring / Notification
SERVICE (3)	SIXTH Service Registry / Services
AGENT (4)	Agent Enabled

CLARITY iWSN & SIXTH Integration

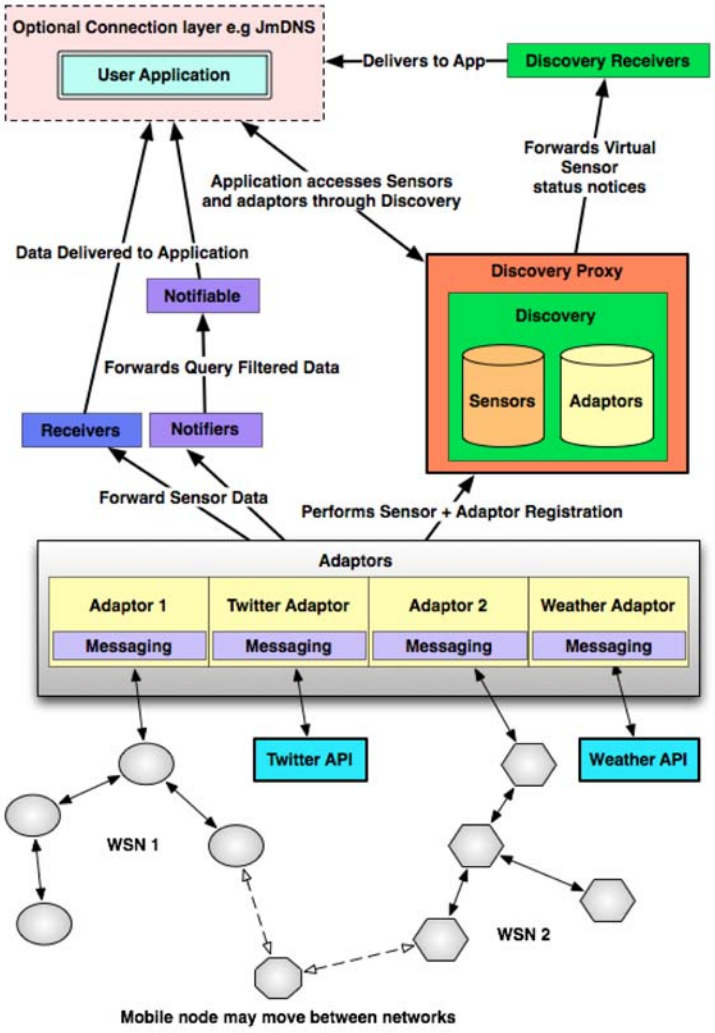




Java and Agent Infrastructure Layers of SIXTH Software Stack accommodated on CLARITY Java-based Sensor Platform

Angove, P., O'Grady, M.J., Hayes, J., O'Flynn, B., O'Hare, G.M.P., & Diamond, D. A., Mobile Gateway for Remote Interaction with Wireless Sensor Networks, IEEE Sensors Journal, Volume: 11 , Issue: 12, Page(s): 3309 - 3310 (2011),

SIXTH Architecture



Adaptors:
Virtual Sensor creation
Sensor-SIXTH integration

Discovery Service:
Secure Sensor Access

Receivers:
Streaming of sensor data

Notifiers:
Filtered sensor data streams

Services:
Data processing / Dissemination

O'Hare, G.M.P., Muldoon, C., O'Grady, M.J., Collier, R., Murdoch, O & Carr, D., Sensor Web Interaction, International Journal Artificial Intelligence Tools, Vol. 21, N2, April 2012., World Scienfic Press

The SIXTH Vision

- Abstraction: Sensor-driven applications abstracted away from the underlying sensor network;
- (Re)tasking: Facilitating dynamic re-tasking of individual sensors and sensor networks to suit shifting demands
- Seamless Integration of Rich Variety of Sensors: Delivering upon an ease of data fusion for physical and cyber based sources.
- Intelligent Reasoning enabling adaptivity of the sensing network.

Jurdak, R., Ruzzelli, A. G., O'Hare, G.M.P. & Higgs, R., Directed Broadcast with Overhearing for Sensor Networks, ACM Transactions on Sensor Networks, Vol. 6, Issue 1, 2010, ACM Press

Jurdak, R., A. G. Ruzzelli, A.G., & O'Hare, G.M.P., Radio Sleep Mode Optimization in Wireless Sensor Networks, IEEE Transactions on Mobile Computing, Vol. 9, No. 7, pp 955-968, April 2010.

Tynan, R. Muldoon, C., O'Hare, G.M.P. & O'Grady, M.J., Coordinated Intelligent Power Management and the Heterogeneous Sensing Coverage Problem, The Computer Journal (Special Issue on Agent Technologies for the Sensor Networks), Vol. 54., No 3., March 2011, Oxford University Press,

CLARITY & Bell Labs Collaboration (CLARaBELLe)

Application Enablement for Sensor Systems

SIXTH Scientific Contributions

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- ✓ Supports the rapid development of a diverse range of Sensor Web applications achieved by SN adaptors and middleware services.;
- ✓ Minimal systems programming for deployment - facilitated via code generation.
- ✓ Treating web-based and physical sensors as equal citizens
- ✓ In-network Intelligence achieved via energy-aware agent-based intelligence embedded in network via integration of Agent Factory.
- ✓ Zero-configuration (plug & play) philosophy.
- ✓ Dynamic re-tasking of sensors and sensor networks.
- ✓ Standards Enabled - OGC Sensor Web Enablement Standards, SML OSGi

OGC
Making Location Count

How SIXTH Compares

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	Heterogeneity	Scalability	Intelligence	Extensibility	Actuation	
SIXTH	Full	Full	Yes	Yes	Yes	
GSN	Full	Full	No	Yes	No	
WSN-WARE	Full	No	No	Yes	Yes	
LSM	Full	Full	Yes	Yes	No	
TinyDB	Partial	No	No	No	Yes	
Impala	Partial	No	Yes	No	Yes	
Agilla	Partial	No	Yes	No	Yes	

A Broader Due Diligence

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System	Category	Energy-Awareness	Scalability	Heterogeneity	Collaboration	Intelligence
Mate	Node-Level	✓	✓	×	×	×
VMStar	Node-Level	✓	✓	×	×	×
Impala	Node-Level	✓	✓	✓	×	×
Sensorware	Node-Level	✓	×	×	✓	×
Abstract Regions	Group-level	✓	✓	×	×	×
Hood	Group-Level	✓	✓	×	✓	×
Cougar	Network-Level	✓	✓	×	×	×
TinyDB	Network-Level	✓	✓	×	×	×
SINA	Network-Level	✓	×	×	✓	×
MiLAN	Network-Level	✓	×	×	×	×
DSWare	Network-Level	✓	✓	×	×	×
Regiment	Network-Level	✓	✓	×	✓	×
Kairos	Network-Level	✓	×	×	✓	×
Software Sensors	Network-Level	×	✓	✓	×	×
DRN	Network-Level	✓	✓	×	×	✓
Lames	Network-Level	✓	✓	✓	✓	×

Conclusions

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- Intelligent decision making
  - policy level decisions based on QoS
  - realised by nodes collaboratively
- Resource-bounded Reasoning
  - utility-aware reasoning
  - varying permitted per cycle cost threshold
- Learning and using Energy-Density-Latency-Accuracy
  - Trade-offs – more nodes is not always better