School of Information Engineering
China University of Geosciences (Beijing)

Energy-Aware Composition for Wireless Sensor Networks as a Service

Zhangbing Zhou

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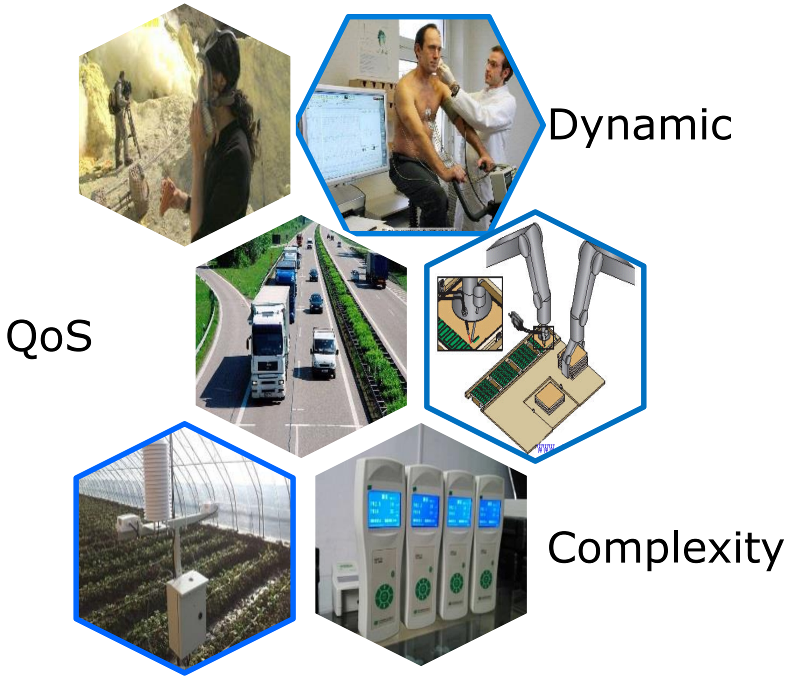
Motivation: Service-Oriented Wireless Sensor Networks

- **Applications and Requirements**
  - Dynamic and pervasive environment (Wireless sensor network)
    - healthcare, military surveillance, planetary exploration …
  - Complexity and coarse-granularity
  - Collective fashion
    - Collaboration of multiple neighboring sensor nodes
  - Applications demanding robustness and reliability
    - **Spatial-temporal-constraint**, **energy-efficiency**, mobility …



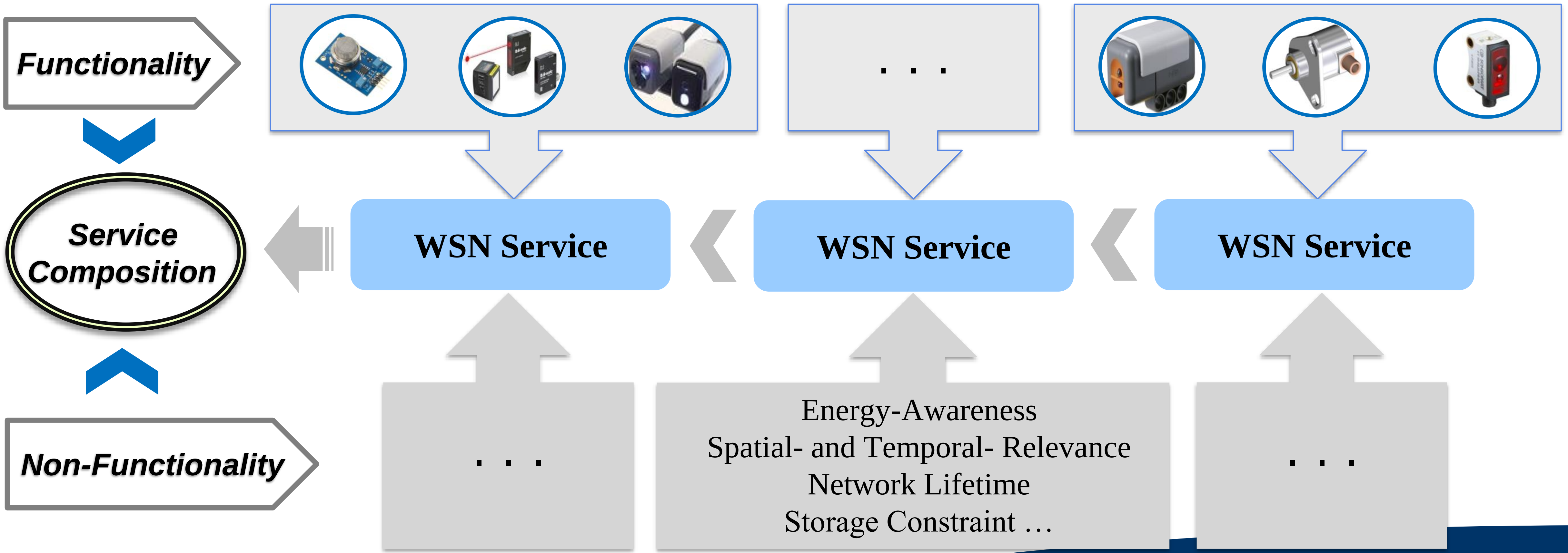
- **Service-oriented paradigm is promising**
  - "*IoT resources can be encapsulated as* ***IoT-based services****, leveraging Device Profile for Web Services, to accomplish complex task*" (S. N. Han, IEEE Internet Computing, 2015)

  - Current approaches mainly examine the framework for the management and monitoring of IoT-resources composition, whereas the composition of IoT-based services is not explored extensively.

Motivation: Service-Oriented Wireless Sensor Networks

- IoT-based Service / WSN Service

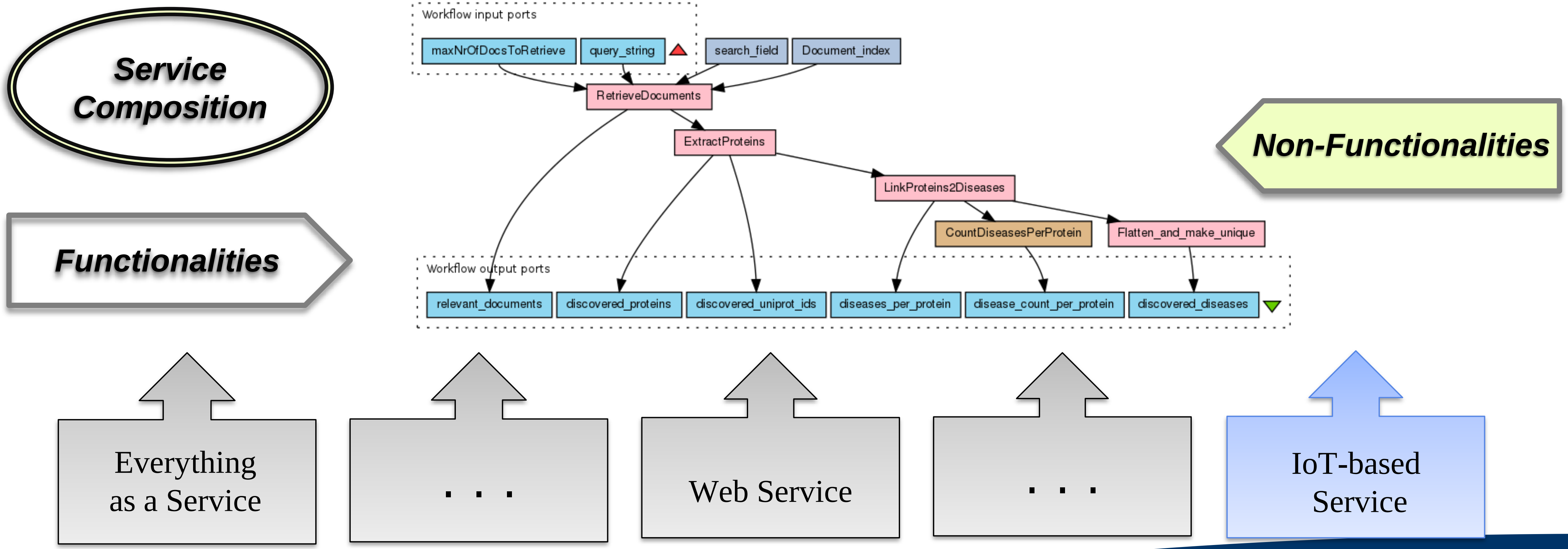
  The functional composition of heterogeneous sensor nodes is a pressing and promising alternative, where the functionality of sensor nodes is encapsulated and represented as a **WSN service**.



Motivation: Service-Oriented Wireless Sensor Networks

- IoT-Resource / WSN-Service Composition

  Connection-awareness and network-lifetime consideration should be important for the composition of WSN services, which has not been examined extensively at this moment, and should be further explored.



Research Challenges

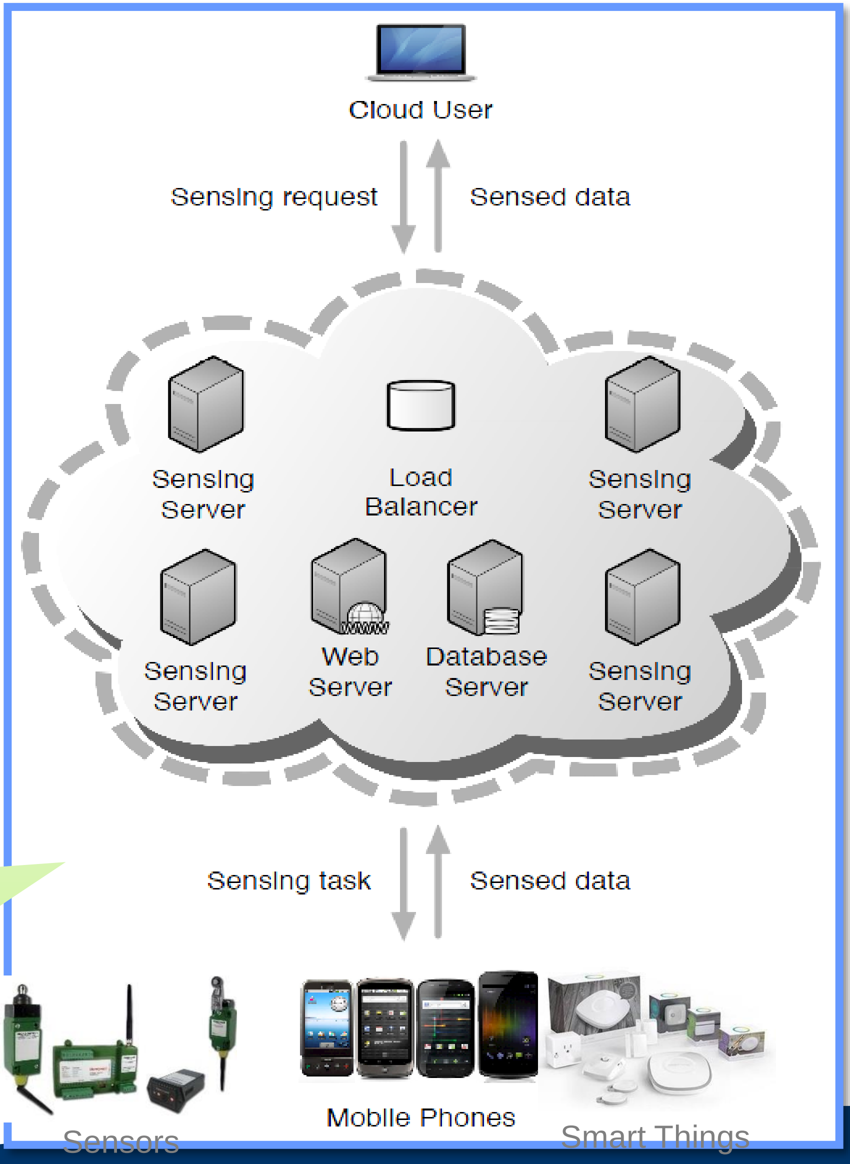
- Context of WSN services
  - Core properties for WSN services
    - Spatial and temporal awareness, and energy efficiency.
  - Current approaches
    - Framework for the management and monitoring of IoT-resources
  - Challenges
    - Service composition while considering properties of WSNaaS.

Wireless Sensor Network as a Service (WSNaaS)

Energy-efficiency | **Spatial-Temporal awareness**

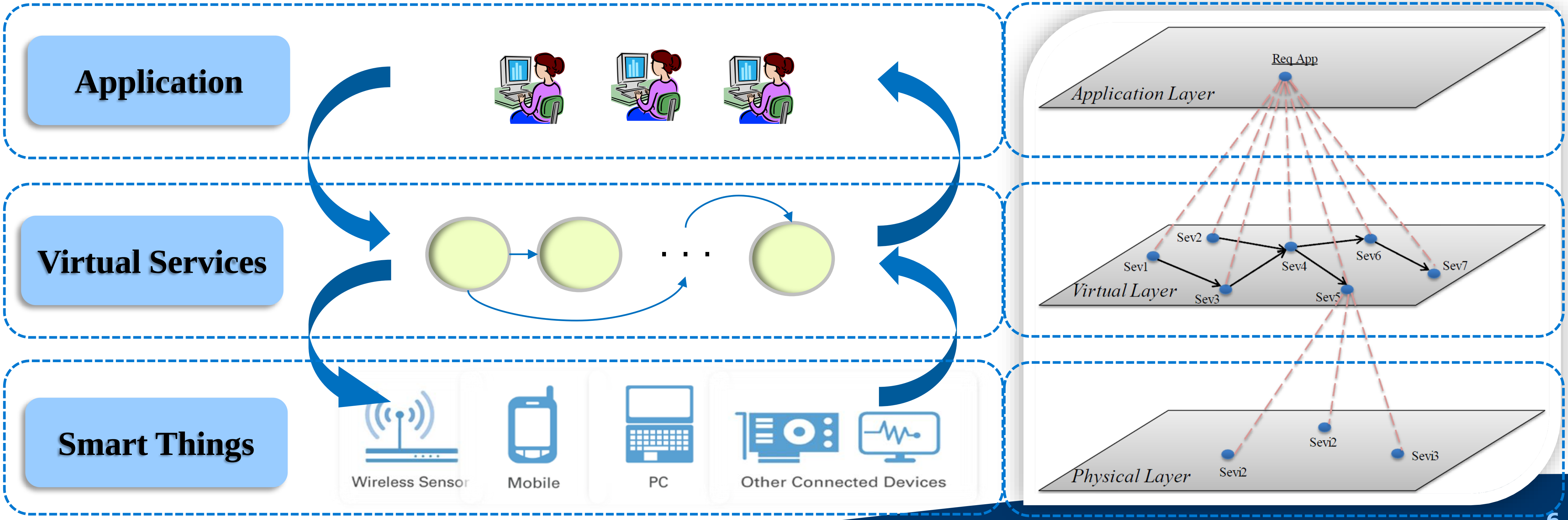
Mobility | **Bandwidth** | **Reliability**

Storage space | **Sense/computation capability**



Approach Overview

- Three-Tier Service-Oriented Framework
  - **Physical Layer**: sensors, phones, and other type of physical devices encapsulated and represented as **WSN services**.
  - **Virtual Layer**: WSN services are categorized into **service classes** according to their functionalities.
  - **Application Layer**: service classes are chained to fulfill the requirement of domain applications.



Service Classes Chaining and Recommendation

- Service Network Construction
  - Directed graph
    - I. Vertex: **Service Classes**.
      - ✓Name
      - ✓Description
      - ✓Operation

Android Phone Sensors

Table 3: Sample service classes corresponding to sensor types specified at https://developer.android.com/guide/topics/sensors/sensors_overview.html.

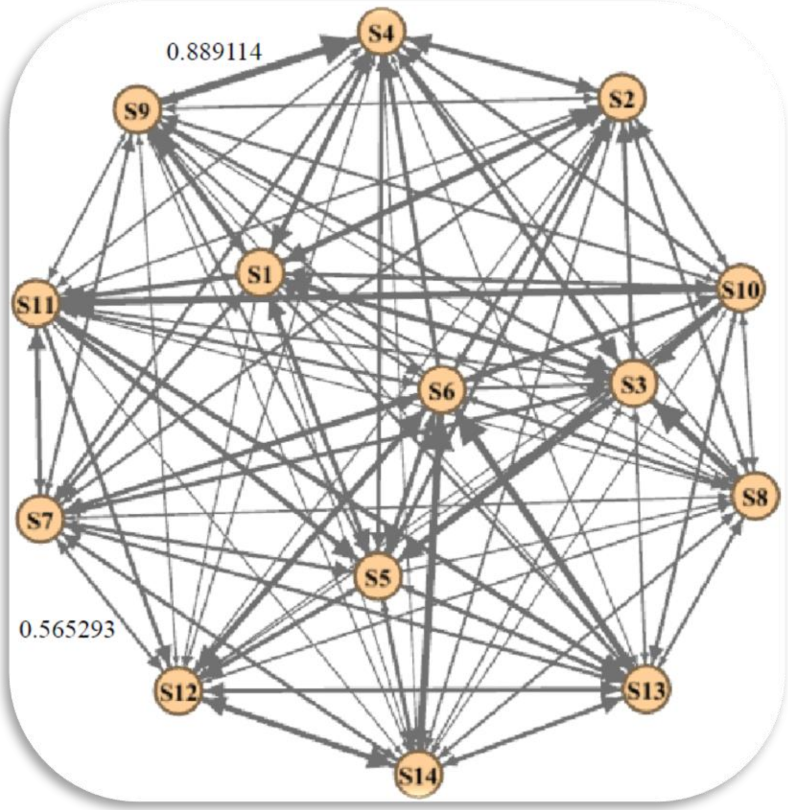
Id	$sev_{cl}.nm$	$sev_{cl}.dsc$
S1	Ambient temperature sensing service	Measures the ambient room temperature in degrees Celsius (°C). Common use is for monitoring air temperatures.
S2	Temperature sensing service	Measures the temperature of the device in degrees Celsius (°C). This sensor implementation varies across devices. Common use is for monitoring temperatures.
S3	Relative humidity sensing service	Measures the relative ambient humidity in percent (%). Common use is for monitoring dewpoint, absolute, and relative humidity.
S4	Light sensing service	Measures the ambient light level (illumination) in lx. Common use is for controlling a light, and adjusting its brightness.
S5	Pressure sensing service	Measures the ambient air pressure in hPa or mbar. Common use is for monitoring air pressure changes.
S6	Gravity sensing service	Measures the force of gravity in m/s^2 that is applied to a device on all three physical axes (x, y, z). Common use is for motion detection (vibration, wobble, etc.).
S7	Magnetic field sensing service	Measures the ambient geomagnetic field for all three physical axes (x, y, z) in μT. Common use is for creating a compass.
S8	Proximity sensing service	Measures the proximity of an object relative to the view screen of a device. This sensor is typically used to determine whether a person is enough closely near the device.
S9	Ambient smog sensing service	Measures the ambient room smog in degrees mg/L. Common use is for monitoring air smog, and fire alarm.
S10	Wind direction sensing service	Measures the wind direction. Common use is for monitoring the wind direction when there are something spread along the wind.
S11	Wind power sensing service	Measures the wind power. Common use is for monitoring the wind power in a weather application.
S12	Accelerometer sensing service	Measures the acceleration force in m/s2 that is applied to a device on all three physical axes (x, y, and z), including the force of gravity.
S13	Rotation vector sensing service	Measures the orientation of a device by providing the three elements of the device's rotation vector.
S14	Gyroscope sensing service	Measures a device's rate of rotation in rad/s around each of the three physical axes (x, y, and z).

Service Classes Chaining and Recommendation

- **Service Network Construction**
  - Directed graph
    I. Vertex: Service Classes.

    II. Edge: direct links
       ✓Invocation relationship between service classes.

    III. Weight: invocation possibility between service classes
       ✓Degree of similarity of the ***names***
         - *Minimum cost and maximum flow algorithm*
       ✓Degree of similarity of the ***descriptions***
         - *xsimilarity*
       ✓Invocation possibility of the ***operations***
         - Name/description similarity of the parameters



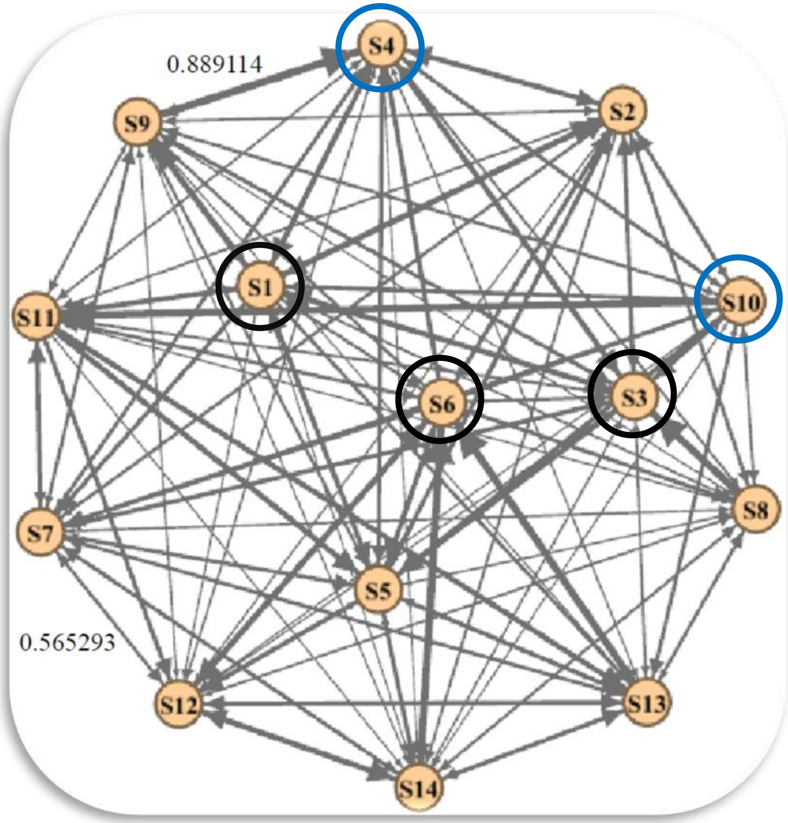
Refer to : Z. Zhou et al, A Sub-Chain Ranking and Recommendation Mechanism for Facilitating Geospatial Web Service Composition. Int. J. Web Service Res. 11(3): 52-75 (2014)

Service Classes Chaining and Recommendation

- Service Classes Chains Discovery and Recommendation

- Text descriptions of requirements
- Starting and ending States

Starting state: *"Gathers data from multiple sensor nodes in a wireless sensor network, which may include temperature, humidity, wind direction, wind power, ambient smog, light, accelerometer, and other sensors commonly used for monitoring fire alarm, and so on. Public reports to generate the accurate current location of the fire in the firehouse."*
Ending state: *"According to the gathered data from corresponding sensors, such as temperature, humidity, ambient smog, wind direction, wind power, light sensors and so on, to generate the current fire region and forecasts of fire spreading in the following time duration. Properly identify the incident, raise the occupant alarm, and then notify emergency response professionals timely."*



Step 1 : Finding starting and ending states.
(*description similarity and invocation possibility*)

Step 2 : Searching candidate service classes chains.
(*depth-first graph search algorithm*)

☆ Service Classes Chain
A sequence of service classes for supporting certain application.

Example service classes chain:

- **S4** *(light sensing service)* →
- **S1** *(ambient temperature sensing service)* →
- **S3** *(relative humidity sensing service)* →
- **S6** *(gravity sensing service)*→
- **S10** *(wind direction sensing service).*

Constraints on WSN Services Composition

- **WSN Services Composition**
  - A sequence of **WSN services**, corresponding to certain ***service classes chain***, for supporting certain applications.
    - ✓ Name
    - ✓ Description
    - ✓ Operation
    - ✓ **Remaining energy**
    - ✓ **Spatial constraint**
    - ✓ **Temporal constraint**

Temporal Constraint:
Based on the overlap between time durations of the request *rq* and a certain WSN service *sev*, i.e., *tpr(rq) and tpr(sev):*

$$tpr_r(sev, rq) = (tpr(rq) \cap tpr(sev)) \div tpr(rq)$$

Spatial Constraint:
Based on the overlap between geographical region of the request *rq* and a certain WSN service *sev*, i.e., *spt(rq) and spt(sev):*

$$spt_r(sev, rq) = (spt(rq) \cap spt(sev)) \div spt(rq)$$

Energy Consumption:
Activation cost of instantiating WSN services

$$E_{inv}(comp(chn)) = f_i \times E_{inv}(sev_i)$$

Communication cost between WSN services

$$E_{com}(comp(chn)) = (leg(comp(chn)) - 1) \times (E_{Tx}(k, d) + E_{Rx}(k))$$

Energy Constraint of a Certain WSN Service:
Residual energy should be more than required to be consumed:

$$eng(sev_i) \geq E_{cst}(sev_i)$$

Residual energy load-balancing:
To avoid over-consumption of energy for any WSN service:

$$lbf(sev_i) = (eng(sev_i) - E_{cst}(sev_i)) \div E_{avg}$$

WSN Service Composition

- WSN Services Composition
  - Formulated as a multi-constrained and multi-objective optimization problem.

OutPut:
Optimal composition of WSN services with respect to the recommended service classes chains.

Fitness Function:

$$fitness(comp(chn)) = w_{min} \cdot Z_{min} - w_{max} \cdot Z_{max} = w_{min} \cdot E(comp(comp(chn))) - w_{max} \cdot (\varphi \cdot lbf(comp(chn)) + \beta \cdot spt(comp(chn)) + \gamma \cdot tpr(comp(chn)))$$

Multiple –Objective/Constraint

1. Maximum Spatial Coverage Overlap
2. Maximum Temporal Relevancy
3. Minimum Energy Consumption
4. Balance Residual Energy

Sufficient Residual Energy

Solution

1. Exhausted mechanism (ExhA)
2. Particle swarm optimization (PSO); Genetic algorithm (GA)

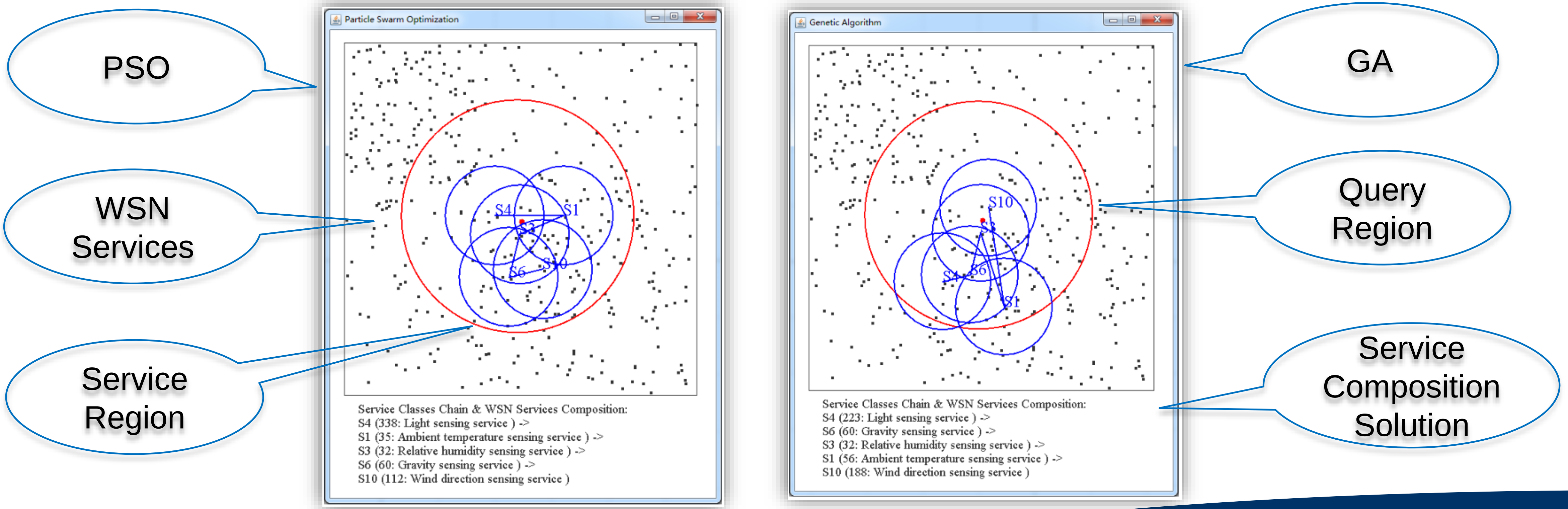
Implementation and Evaluation

- ## Service Classes Chains & WSN Services Composition

Sample service classes chain and one of the WSN services compositions generated through applying PSO and GA.

Service classes chain: S4 → S1 → S3→ S6 → S10
WSN service composition: *338→ 35 → 32 → 60 → 112*

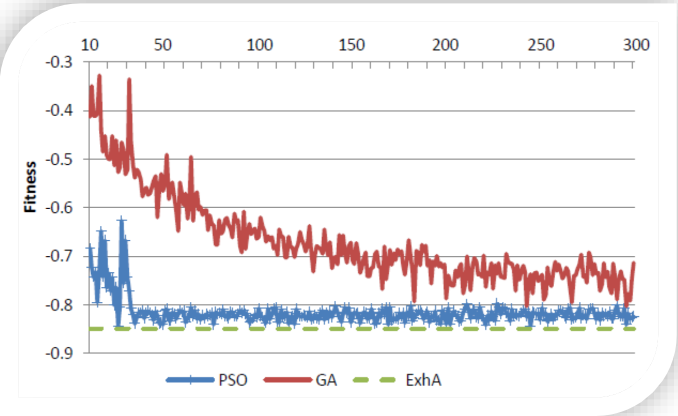
Service classes chain: S4 → S6 → S3 → S1 → S10
WSN service composition: *223 → 60 → 32 → 56 → 188*



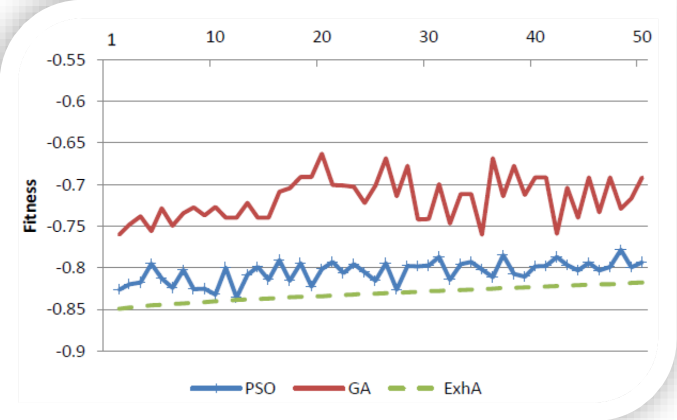
Implementation and Evaluation

- Experimental Evaluation

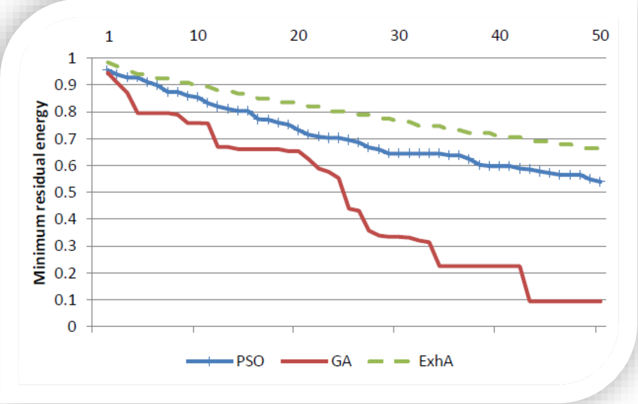
Fitness – Different iteration times



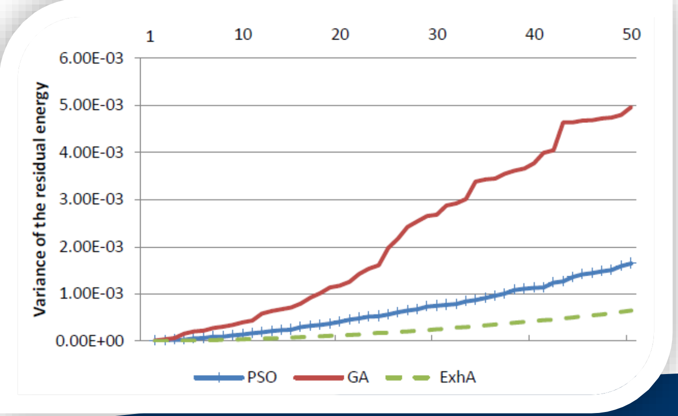
Fitness – Different execution times



Minimum Residual Energy



Variance of Residual Energy



Conclusion

- **IoT-based Service / WSN service**
  - Services encapsulated from sensor or mobile devices
    - Spatial and temporal constraints
    - Energy awareness
- **Wireless Sensor Network as a Service**
  - Service configuration, discovery and composition
    - Construct service network
    - Service classes chaining and recommendation
  - Composition of WSN services
    - Consider constraints of WSN services
    - Formulated as a multi-constrained and multi-objective optimization problem
  - Solution
    - PSO / GA / GWO / Exhausted Algorithm
- **Future Work**
  - Domains for service computing community to contribute
    - WSN as a service, Sensing/… as a Service
    - Service composition, reliability, QoS, …

ELSEVIER

Future Generation Computer Systems

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Energy-aware composition for wireless sensor networks as a service

Zhangbing Zhou [a, d], Deng Zhao [a], Lu Liu [b], Patrick C.K. Hung [c]

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Highlights

- Propose a three-tier service-oriented framework for WSNs.
- Service classes chains discovery and recommendation is developed.
- Multi-objective and multi-constrained optimization is adopted for WSN services in service classes in chains.