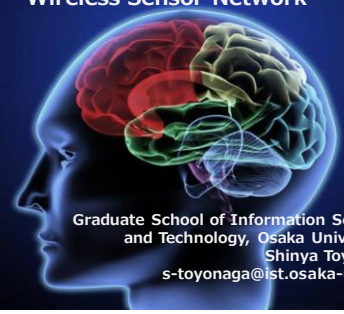
Brain-inspired Method for Constructing a Robust Virtual Wireless Sensor Network



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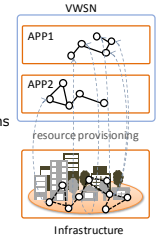
Research background

- In future IoT, wireless sensor networks (WSNs) are expected to be integrated as infrastructure.
  - Coexistence of heterogeneous networks
  - Flexibility for satisfying various traffic demands

Virtualization of WSN is one of key solutions.

- Virtual wireless sensor network (VWSN)[1]
  - Separation of physical infrastructure and applications
  - Constructing VWSN for each application
    - Flexibility : dynamical resource assignment
    - Heterogeneity : transparent protocol



Problems and research objective

- Various environmental changes occur in VWSN.
  - Addition or removal of nodes or links
  - Resource assignments for new applications

We propose a method for constructing a robust VWSN topology against environmental changes.

- How to construct a ***robust*** VWSN?
  - The main objective of existing research is to provide a framework of sharing physical substrates.

We use the latest knowledge of **human brain networks**, which provide important hints of robustness.

Brain networks[2]

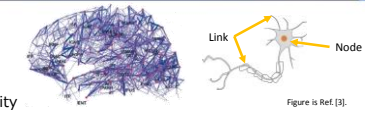


Figure is Ref.[3].

- Robust connectivity
  - Brain works although about 9,000 neurons die per a day.
- Adaptive evolution
  - Brain networks negotiate metabolic cost and communication efficiency.
    - When cognitive demands increase, costly long-distance high-speed links are constructed.
    - When cognitive demands decrease, short-length links tends to be constructed and maintained.

Brain networks should have a meaningful structure for robust and efficient information processing.

Structural properties of brain networks[2]

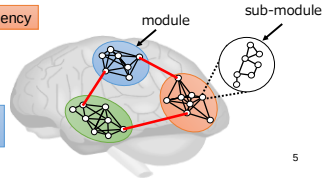
- Hierarchical modular community structure
  - Densely connected within module and sparsely connected between modules
  - Each module consists of sub-modules hierarchically

High robust connectivity within modules

- Small-world properties
  - Short average path length and high clustering coefficient

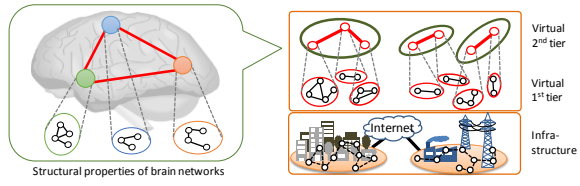
High communication efficiency

Introducing these properties into VWSN topology



VWSN inspired by structural properties of brain network

- We construct a hierarchically modular VWSN
  - Each module has small-world properties
  - Modules are integrated hierarchically

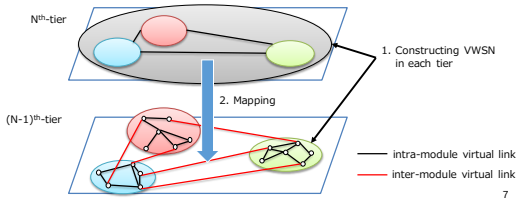


Structural properties of brain networks

Further investigation about which modules to connect each other by virtual links to get robustness in global area is necessary

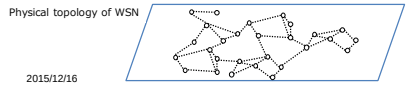
Overview

0) Defining the 1st-tier modules so that service demands can be satisfied
1) Constructing an Nth-tier VWSN that has small-world properties
2) Mapping the endpoints of virtual links to node pairs



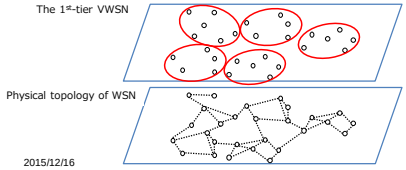
How does our proposal work?

- In the case of two-tiered VWSN topology construction



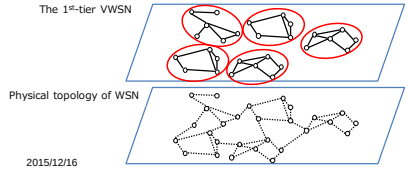
How does our proposal work?

0) Defining the 1st-tier modules so that service demands can be satisfied



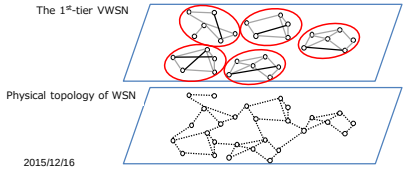
How does our proposal work?

1) Constructing a 1st-tier VWSN that has small-world properties
   a) A 1st-tier virtual link is added between nodes when they are connected by a physical link.



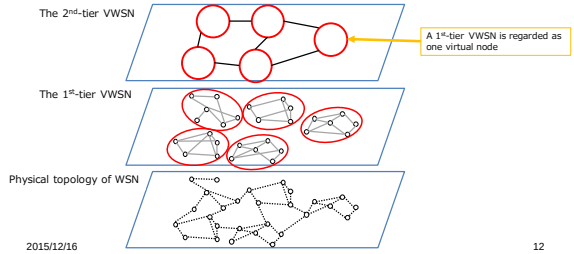
How does our proposal work?

1) Constructing a 1st-tier VWSN that has small-world properties
   b) New 1st-tier virtual link is added so that 1st-tier VWSN has small-world properties.



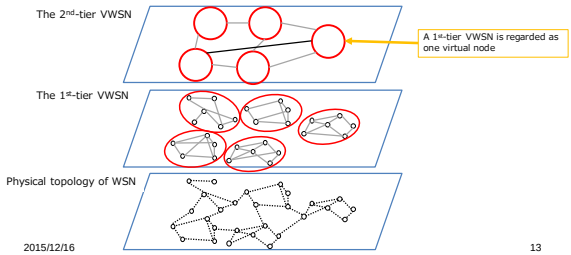
How does our proposal work?

1) Constructing a 2nd-tier VWSN that has small-world properties
   a) A 2nd-tier virtual link is added between 1st-tier VWSNs when they are connected by a physical link in infrastructure.



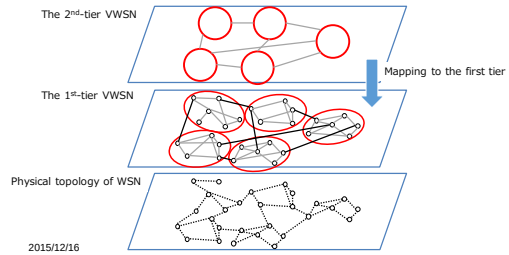
How does our proposal work?

1) Constructing a 2nd-tier VWSN that has small-world properties
   b) New 2nd-tier virtual link is added so that 2nd-tier VWSN has small-world properties.



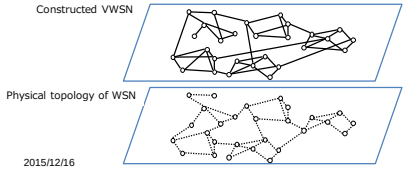
How does our proposal work?

2) Mapping the endpoints of 2nd-tier virtual links to node pairs



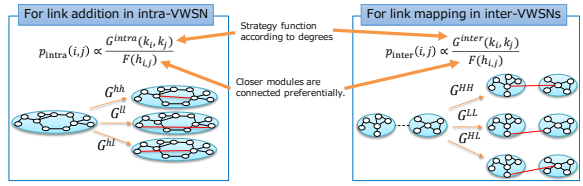
How does our proposal work?

- Construction process of VWSN is completed.



How to add a virtual link?

- We use a preferential attachment rule according to distance constraints and degree.

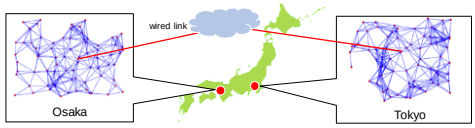


hh, HH : connects higher degree VWSNs
ll, LL : connects lower degree VWSNs
hl, HL : connects higher and lower degree VWSNs

We investigate 9 sets of results, resulting from combination of two strategies.

Simulation settings

- Network model
  - Two sensor networks, each comprising 150 sensor nodes, are connected by one wired link.



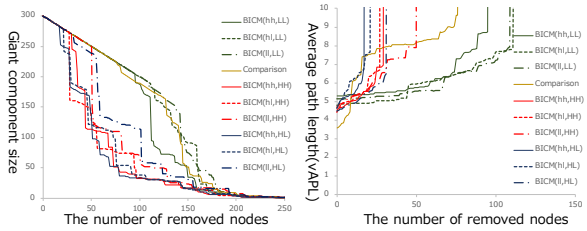
  - The minimum unit module is defined by Newman algorithm[4] which divides network into modules to maximize the modularity.
  - Three-tiered VWSN is constructed in our simulation.
- Comparison : Method for constructing a small-world sensor network based on clustering[5]
  - We regard the constructed topology as a VWSN topology.

Evaluation metric

- Robustness of connectivity
  - The decrease in giant component size, the number of nodes belonging to the maximally connected subgraph, when nodes are removed in the order of decreasing degree
- Robustness of average path length of VWSN (vAPL)
  - The increase in vAPL when nodes are removed in the order of decreasing degree

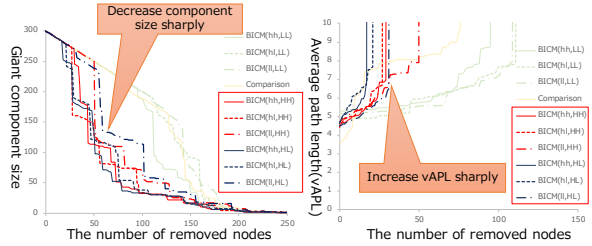
Robustness

- Our proposal is defined by two arguments, denoted by BICM(intra,inter).
  - Each color shows the method of virtual link mapping (inter).



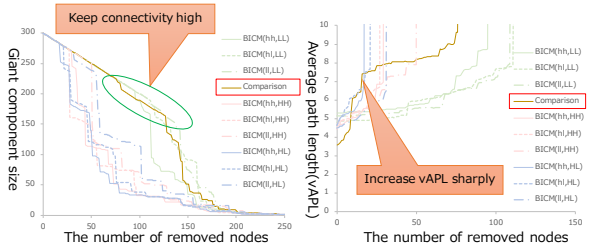
Robustness

- When one of the endpoints of virtual links are mapped to higher degree module, VWSN topology gets vulnerable.



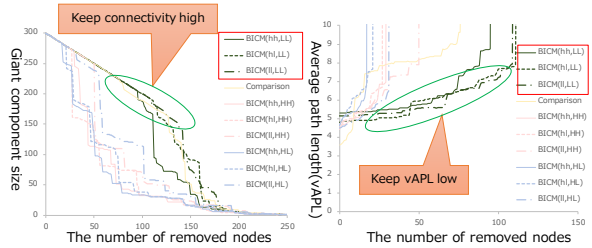
Robustness

- Comparison realizes high robustness in terms of only connectivity.



Robustness

- When the endpoints of virtual links are mapped to lower degree modules, VWSN topology garners high robustness.



Conclusion and Future work

- Conclusion
  - We propose a method for constructing highly robust VWSN topology by integrating small-world network hierarchically.
- Future work
  - Method for assigning virtual link to physical resources
    - Directional beam, omni-directional high power transmission or multi-hop with priority
  - Algorithm for configuring VWSN topology according to traffic demand.

References

[1] Md. MotaharuI Islam et. al, “A Survey on Virtualization of Wireless Sensor Networks”, Sensors, vol.12, pp. 2175-2207, Nov. 2012.
[2] E. Bullmore et. al, “The economy of brain network organization”, Nature Reviews Neuroscience, vol.13, pp. 336-349, May 2012.
[3] Olaf Sporns, “Networks of the Brain”, MIT press, 2011.
[4] M. E. Newman, “Modularity and community structure in network”, PNAS, vol.103, pp. 8577-8582, Apr. 2006.
[5] R. Agarwal et. al, “Achieving small-world properties using bio-inspired techniques in wireless sensor networks”, The Computer Journal, vol.55, pp. 909-931, Mar. 2012.