National Institute of Information and Communications Technology

Center for Information and Neural Networks

インパルス無線によるInternet of Nanothingsの実現に関する一検討

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電波有効利用促進型研究開発　先進的電波有効利用型
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Internet of Things

It's a smart world? [Economist, 2010]]

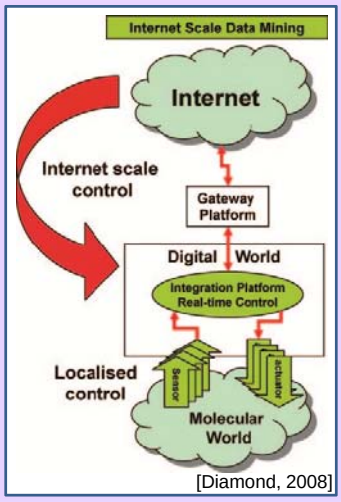
'The real and the digital worlds are converging, bringing much greater efficiency and lots of new opportunities'

Real world	Digital world
Full of sensors, picking up everything from movement to smell	Structure built of software - takes in all that information and automatically acts on it

Increase control of real world

Internet of Nano-Things

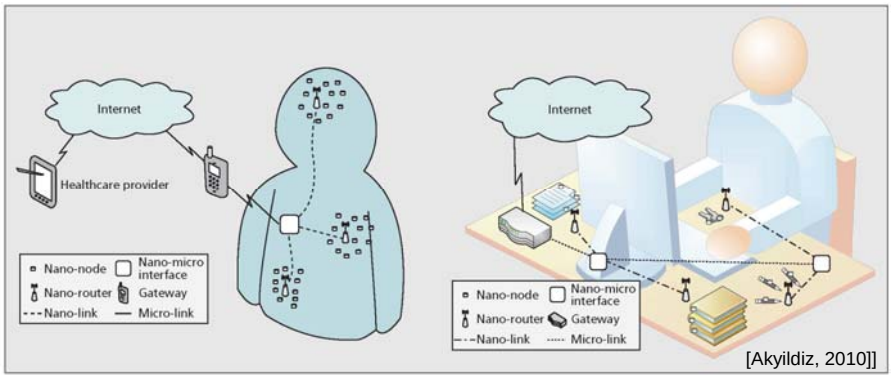
Internet of Nano-Things



[Diamond, 2008]

- Towards a digital world that can sense, interpret, and control real world at the molecular level (Diamond et al., "Wireless Sensor Networks and Chemo-/Biosensing, 2008)
- Requires huge number of sensor nodes with low cost and zero energy consumption

Internet of Nano-Things

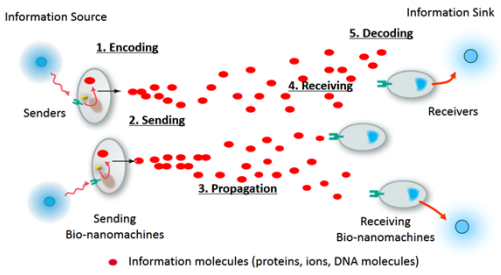


[Akyildiz, 2010]]

- More data on a smaller scale
- Connect to the Internet

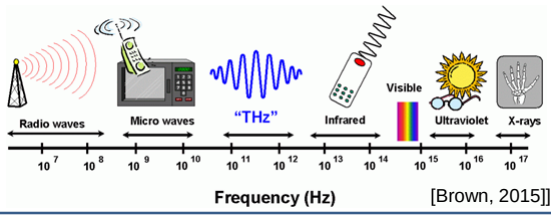
Internet of Nano-Things

Molecular



[Nakano, 2015]]

Electro-Magnetic

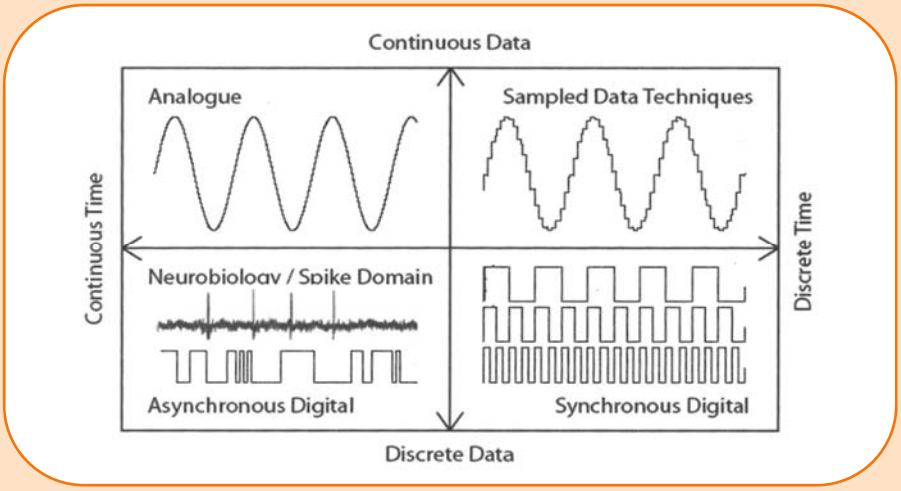


[Brown, 2015]]

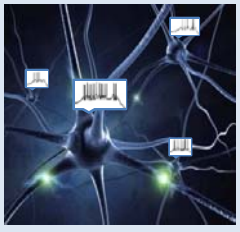
Scenario

- Large # nodes with wireless over very short ranges: only small # (say 10's) of nodes covered
- Energy harvested from environment
- Low data rates
- Nodes extremely simple: small memory
- No active interactions between nodes, no routing
- Asynchronous communication, colliding signals ignored
- Integrated sensing and in-network processing

Signaling



Why *Spiking* in Wireless Sensor Networks?



- Consistent platform based on spiking: sensing, processing, communication, data fusion, so less circuitry needed for conversion
- Extremely low power consumption: potential for battery-less sensor nodes (energy harvesting)
- Small size, since no batteries needed and circuitry limited
- (Limitation is in antenna size, but it may be possible to use the body to which sensor node is attached as antenna)
- Compatible with Impulse Radio
- Neuro-inspired data fusion algorithms

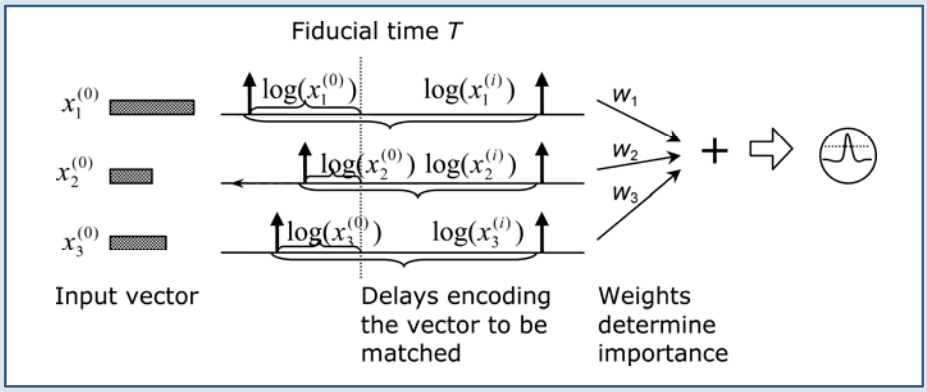
Rate Coding

Averaged Spiking Activity

- Averaged over time: Time window
- One neuron's spiking sequence:

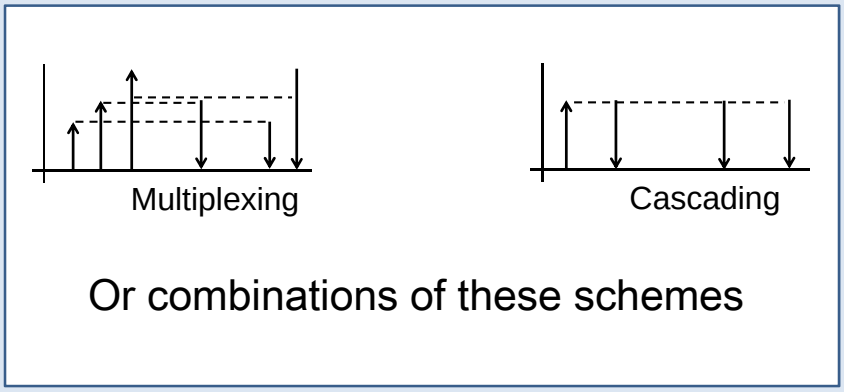
- Averaged over space: average of many neurons in short time

Encoding Analog Values as Spiking Times



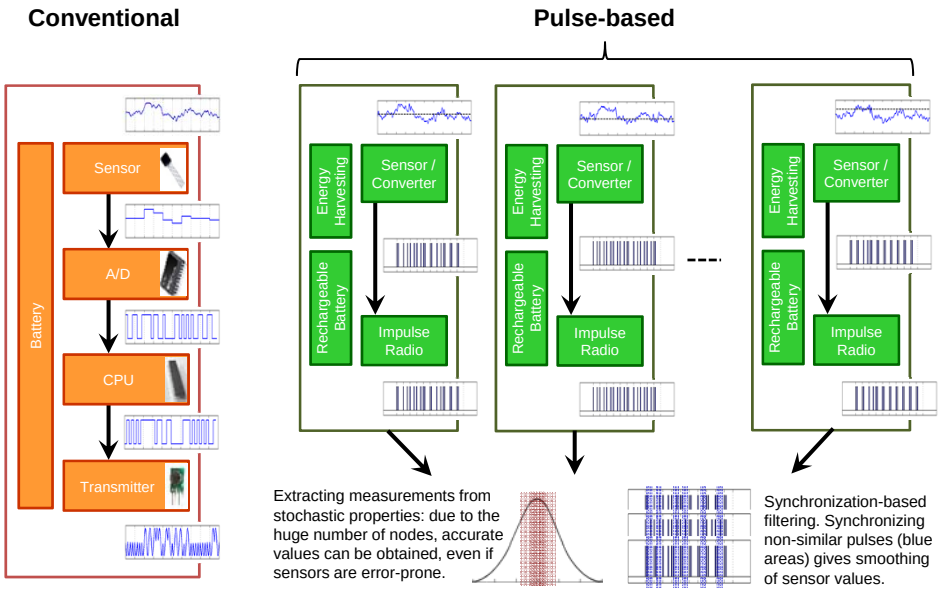
[Hopfield, "Pattern recognition computation using action potential timing for stimulus representation", Nature 376, 1995]

Communication through Silence

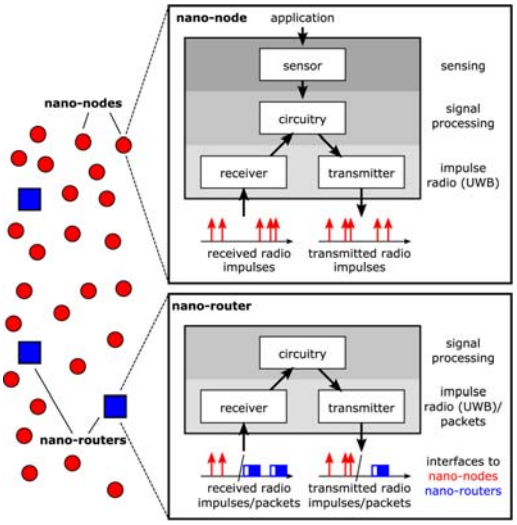


[Zhu, “Challenges: Communication through Silence in Wireless Sensor Networks”, Proc. ACM MobiCom, 2005]

Conventional vs. Pulse-based



Nano-Nodes and Nano-Routers



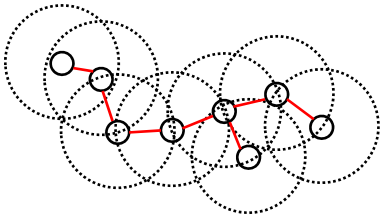
Nano-nodes:

- Smallest size
- Spiking signaling
- Not packet-based
- Extremely simple
- Limited range to each other

Nano-routers:

- Size a bit larger
- Spiking & Analogue signaling
- Packet-based
- Connect to each other and nano-micro interfaces

Random Geometric Graphs



Random Geometric Graphs

- Random geometric graphs very suitable to model wireless networks, since they are based on embedding of graphs in our Euclidian space
- We assume that our random geometric graphs are connected (only one connected component)
- Critical radius for which network is connected with high probability (with N→ ∞):

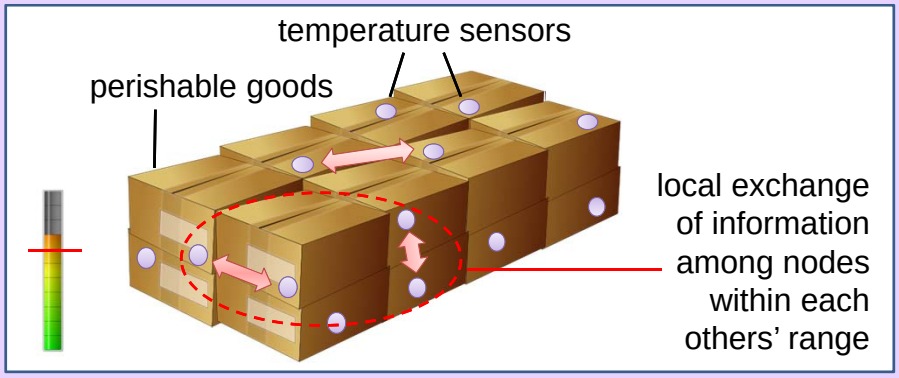
$$r_c = \sqrt{\frac{\ln(N) \pm O(1)}{\pi N}}$$

Consensus and Gossiping

- Nodes are so simple that they have no routing table, etc. Multi-hop routing not supported
- Only local interactions between nodes allowed (gossiping)
- Restrict required information to its essence (statistics)
- Spread essence of information over all nodes
- This can then be read out from any node

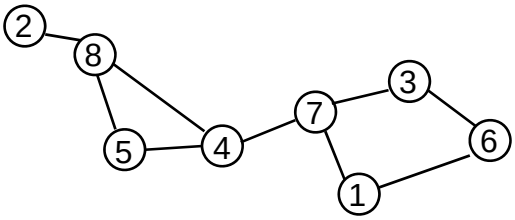
Rather than extracting precise information from a specific node, we determine the essence of information in sensor network as part of process in which it gradually diffuses over the network

Max-Consensus Example: Monitoring Critical Temperature

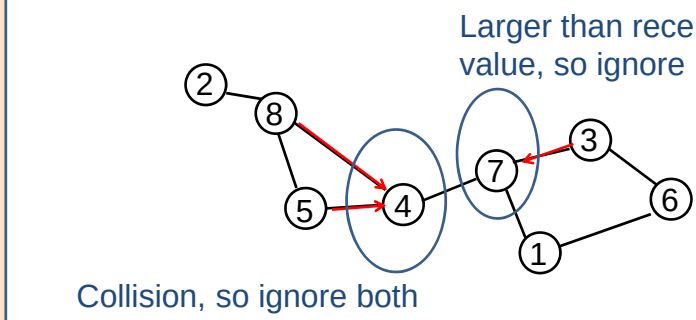


- No centralized control, yet read-out at destination of transport should be possible from any node

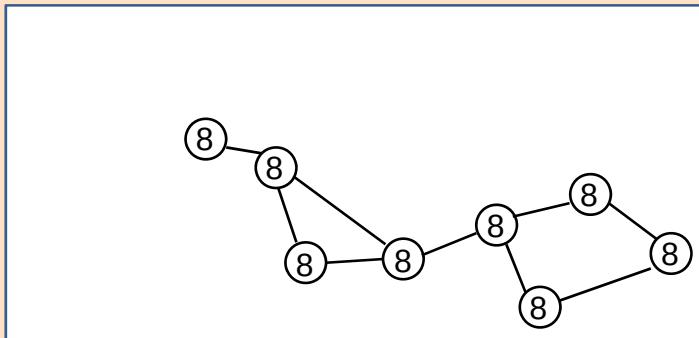
Consensus on maximum



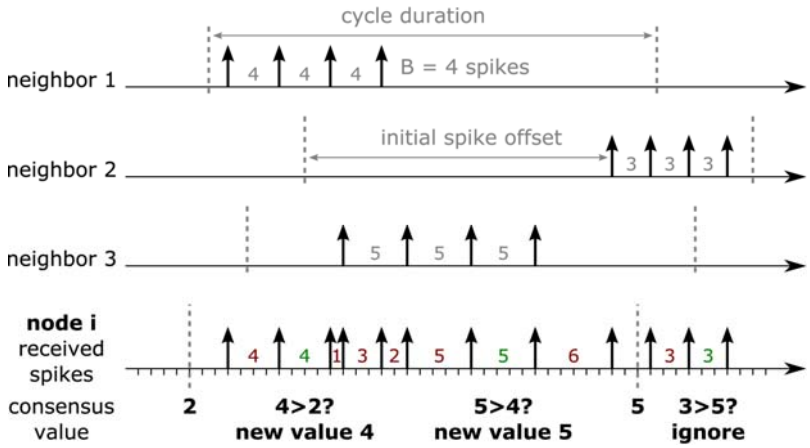
Consensus on maximum



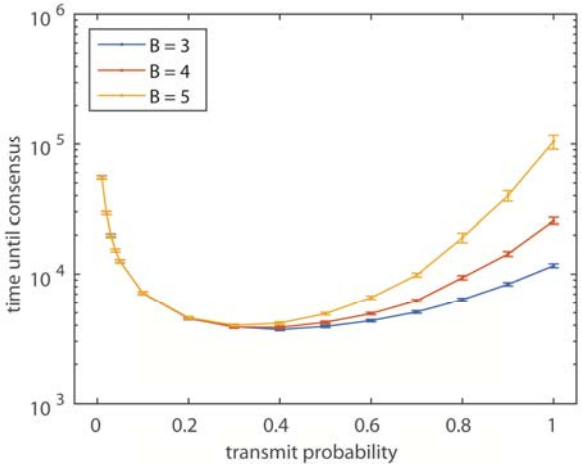
Consensus on maximum



Consensus on maximum



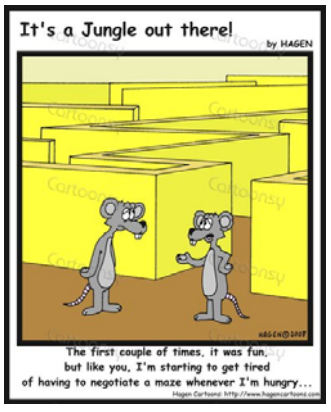
Consensus on maximum

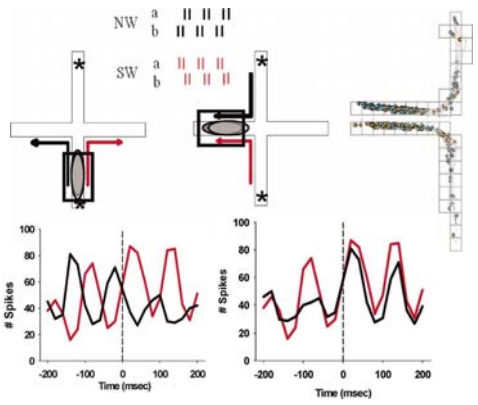


Consensus on maximum

1. **Decentralized processing of data**: nodes are aware of direct neighbors within a small range and receive information from them in a listen-only mode without explicit acknowledgments to neighbors
2. **Data fusion and consensus**: create required information in condensed form, while diffusing it over the network so that it will eventually be available in all nodes
3. **Encoding of signals by spikes**: from the sensing stage to the transmission stage in a consistent way

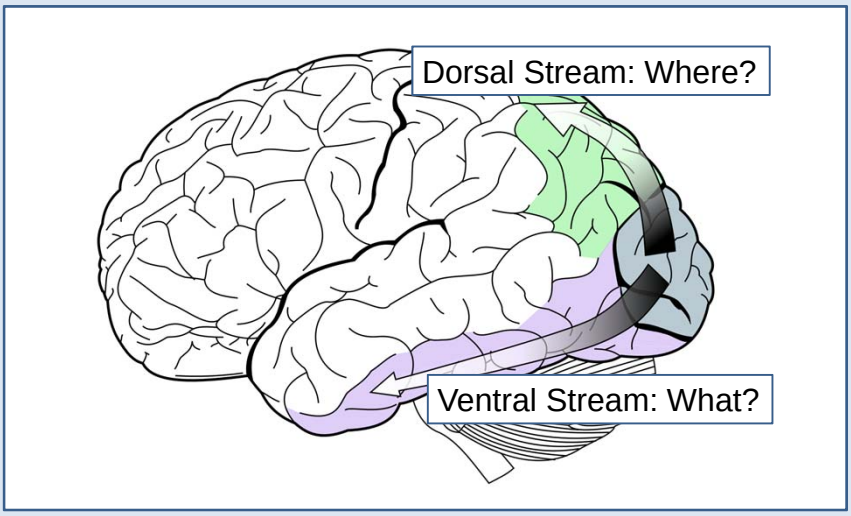
How about the Where?



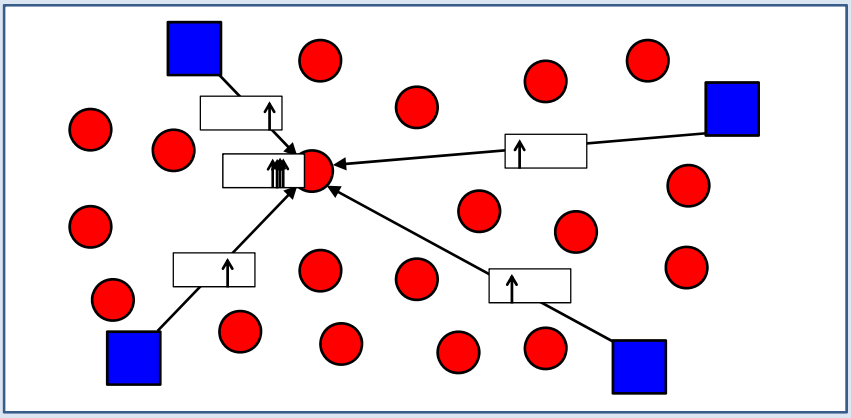


[Shapiro, PNAS 103(11), 4287 (2006)]

What and Where Streams in the Brain



Other Spiking-Based Algorithms: addressing



- Timing pulses so that they arrive approximately at same time
- Node with quick succession of spikes knows it is being addressed: polychronous timing