Nanoscale Communications: Applications, Protocols, and Simulation Tools

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Nano scale communications

• Enormous advancements of nanotechnologies → possibility to deploy nanometric devices

• Different communication paradigms (EM in the THz band, molecular, etc.)

• Revolutionary transition from the Internet of Things (IoT) to the Internet of Nano-Things (IoNT)

• Emerging applications in ICT, biomedical, industrial, and military fields
Telematics Lab related activities

Communication platform for massive multicore architectures

Protocol stacks for **Body Area Nano Networks**

Simulation tools

**Standardization** activities

IEEE PROJECT

P1906.1 - IEEE Draft Nanoscale and Molecular Network Systems

http://telematics.poliba.it/nano-sim
• Chip Multi Processor → hundreds/thousands processor cores inside a single chip (many-core era)

• Parallel instructions → intensive interaction among cores (synchronization, data coherency, data consistency); broadcast communications

• Available solutions
  – Network on Chip (communication latencies and power consumptions issues)
  – Photonic Network on Chip (criticalities related to scalability, power consumption, and topological constraints)
  – Wireless network on Chip (impossibility to install an antenna for each core)
Emerging approach: **Graphene-based Wireless Network on Chip (GWNoC)**

**Pro:**
- Graphene-based nano antennas can be integrated in each processor core
- Extremely high data transmission rates (Tbps)
- Support for a massive data exchange

**Cons:**
- Possible collisions in the shared channel

We need to design a robust communication platform that guarantees low delay and extremely low PLR
Two communication interfaces (wired plane and wireless plane)
[NoC] Proposed hybrid architecture

- Packets are firstly broadcasted through wireless plane extremely high throughput)
- Unicast ACK delivered through the wired plane (low rate)
- Wireless packet retransmissions (after a time out)
- Unicast delivering of unacknowledged packets to specific cores through the wired plane
[BANNET] definitions

- **Wireless Nano Sensor Network (WNSN)**
  - Network of nanometric devices equipped with sensing communication capabilities
  - Nano scale EM communication in the THz band

- **Body Area Nano Networks (BANNET)**
  - WNSN implanted in the human body for collecting diagnostic information and tuning medical treatments
Nanonodes have **limited power capabilities**
- ultra-nanocapacitor accumulates up to **800 pJ** of energy
- TX energy (only for symbol 1) = 1 pJ; RX energy = 0.1 pJ
- a full battery charge allows the transmission **200 bytes** (symbols equiprobable)

Possibility to recharge the capacitor with **piezoelectric nanogenerators**

\[
E_{cap}(n_c) = \frac{1}{2} C_{cap} V_{cap}^2(n_c)
\]

\[
V_{cap}(n_c) = V_g \left(1 - e^{-\frac{n_c \Delta Q}{V_g C_{cap}}}\right)
\]
BANNET interacts with external macro systems (i.e., monitoring devices); rate of external requests $\lambda$

- How routing the request to the most suitable node (and avoid waste of energy)?
• Energy-harvesting scheme
• Handshake mechanism for retrieving the energy level of nanonodes
The routing protocol aims at maximizing the total energy in the cluster estimated at the next step, i.e., $$t_{k+1} = t_k + 1/\lambda$$

$$\max_i \{E^{tot}(t_k + 1/\lambda)\}$$

The amount of energy that each nanonode will have in $$t_{k+1}$$ is computed considering:
- current energy level
- energy required to receive the request messages
- energy required to transmit the answer (only if the node is selected)
- energy harvested in $$\Delta t = 1/\lambda$$

$$E_i(t_k + 1/\lambda) = E_i(t_k) - E^{rx}(N_r) - \beta_i E^{tx}(N_a) + H_i(t_k)$$
• The packet is transmitted towards the node having the highest energy level
Results presented in

Results presented in

[TOOL] The NANO-SIM simulator

• Reference papers

• Main features
  – nano scale EM communications
  – TS-OOK modulation scheme
  – nanonode, nanorouter, and nanointerface devices
  – Some MAC and routing protocols
  – CBR and poisson-based applications
• **P1906.1** - IEEE Draft Recommended Practice for Nanoscale and Molecular Communication Framework


• Definition of a general communication framework (which covers both molecular and electromagnetic communication schemes)
  – Focus on PHY layer
  – Description of components and entities involved into the communication process

• Definition of metrics (for the performance evaluation)

• **Implementation of a reference code**
Future works

- Characterization of nano scale communication in the human body
- Channel capacity and optimal transmission schemes for molecular communications
- Optimal transmission schemes enabling the Internet of Nano-Things
- Hybrid approaches (EM + mol)
- Further involvement in standardization activities
Many thanks for your attention!

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The computation of $H_i(t_k)$ is complex due to the nonlinearity characterizing the energy harvested model.

Number of charging cycles required to reach the energy level stored by the $i$-th node at the end of the request/response mechanism:

$$\bar{n}_{c,i} = -\frac{V_g C_{cap}}{\Delta Q} \ln \left( 1 - \sqrt{\frac{2[E_i(t_k) - (N_r/10 + \beta_i N_a w)E_{p}^{tx}]}{C_{cap} V_g^2}} \right)$$

since $f_c/\lambda$ represents the number of charging cycles between two consecutive requests, $H_i(t_k)$ can be evaluated as

$$H_i(t_k) = E_{cap}(\bar{n}_{c,i} + f_c/\lambda) - E_i(t_k) - (N_r/10 + \beta_i N_a w)E_{p}^{tx}$$

$$= \frac{1}{2} C_{cap} V_{cap}^2 (\bar{n}_{c,i} + \frac{f_c}{\lambda}) - E_i(t_k) - (N_r/10 + \beta_i N_a w)E_{p}^{tx}.$$
In conclusion, the maximization problem is rewritten as

$$\max_i \left\{ \frac{1}{2} C_{cap} \sum_i V_{cap}^2 (\bar{n}_{c,i} + f_c/\lambda) \right\}$$