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Influence of beta and source packet rate on electromagnetic nanocommunications

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Introduction

- **Internet of Things (IoT):**

  Billions of devices (computers, sensors, etc.)

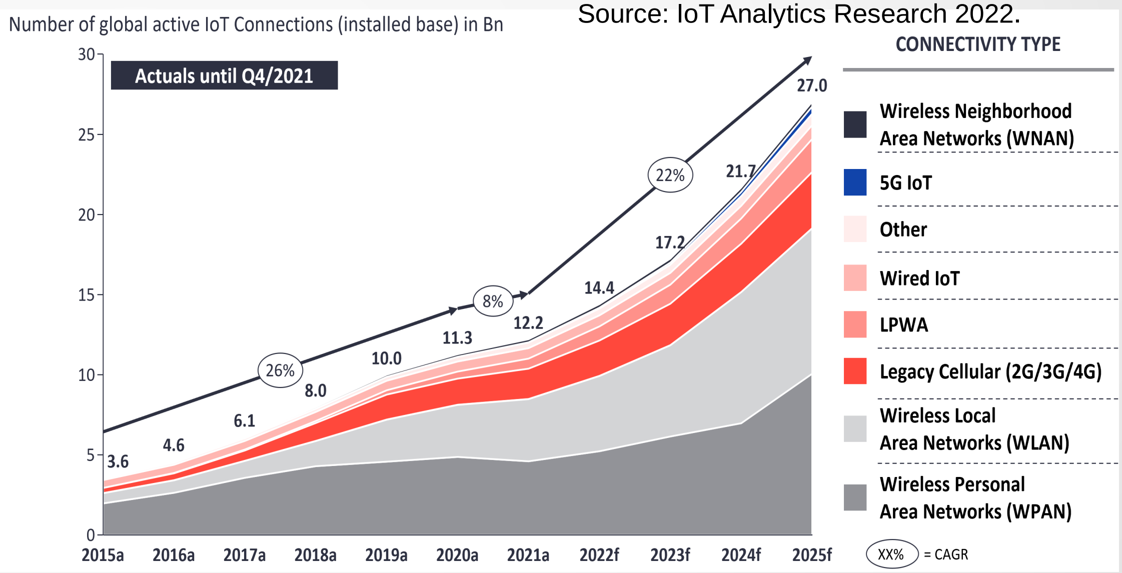
  → enable **smart** applications.

- **Internet of Nano Things (IoNT):**

  Nanodevices

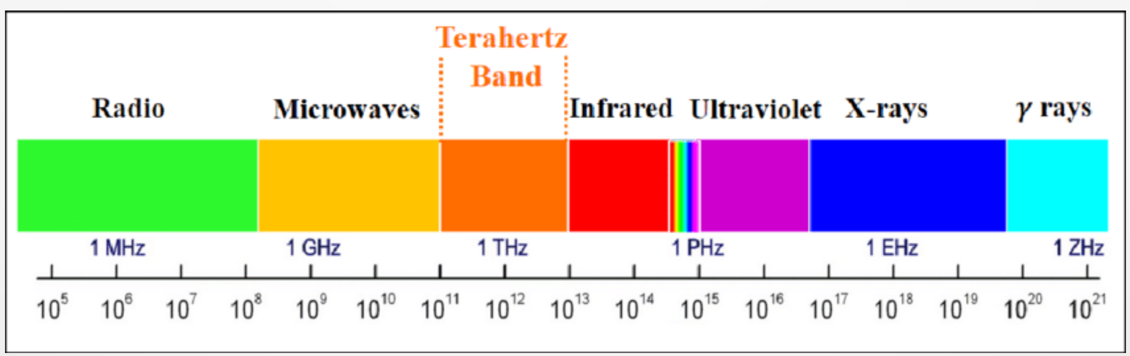
  → enabled by nanotechnology.

Source: IoT Analytics Research 2022.



Electromagnetic Nanonetworks

- Introduced by Jornet in **2010**.
- Networks of **nanodevices**.
- **THz** band (0.1-10 THz).
- High data rates (up to few **terabits per second**).
- Resource-**constrained** nanodevices.
- **Large** network size (e.g., 10^3 to 10^9 nodes).
- High node **density** (e.g., 10^2 or 10^3 of neighbors).



The Terahertz band. Source: Towards nanoscale interconnect for system-on-chip.

Requirements	Software-defined metamaterials Gen. 1	Software-defined metamaterials Gen. 2	Wireless robotic materials	In-body communication	On-chip communication
Network size	10^3 to 10^6	10^9	10 to 10^6	10^3 to 10^9	Up to 10^3
Node density	100 to 10000 nodes per cm^2		1 to 100 nodes per cm^2	$>10^3$ nodes per cm^3	10-100 per mm^2

Applications' requirements of nanonetworks. Source: Survey on Terahertz Nanocommunication and Networking: A Top-Down Perspective.

β and congestion

Relationship between

node symbol rate **β**, **source packet rate**

and

congestion, collisions

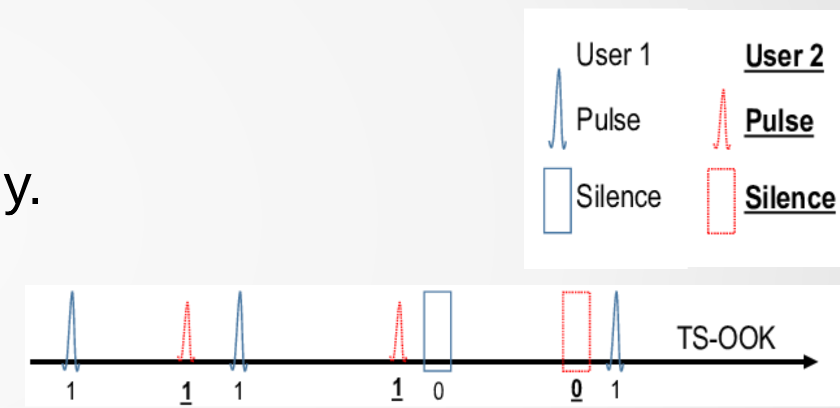
β: Data modulation schemes

- **Nanonetworks: No Carrier** modulations.
- Time Spread On-Off Keying (**TS-OOK**):
  - **Binary:**
    - **Bit 0**: silence without energy.
    - **Bit 1**: pulse for **T_p= 100 fs** with energy.

      → Reduce **collisions**

      (bit 0 is replaced by a bit 1).
  - Inter-bit duration **$T_s > T_p$:**

    → **Multiple packets in parallel ≤ MCR.**
  - Symbol rate **$\beta = T_s/T_p = 1000$:**
    - **Energy harvesting** applications.
    - **Synchronization**: bits decoded at precise times at receiver.

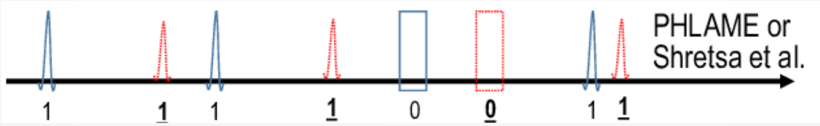


Comparison between modulations. Source: Survey on terahertz nanocommunication and networking: A top-down perspective.

β: Data modulation schemes

Rate Division TSOOK (**RD TS-OOK**) or PHLAME:

- **Problem with TS-OOK**: multiple users transmit with same β + collide in one bit → collide in all bits.
- **Proposition**: **Co-prime β** to transmitters.



Comparison between modulations. Source: Survey on terahertz nanocommunication and networking: A top-down perspective.

Congestion: in nanonetworks

Causes:

- **Wide THz** shared channel **X**
- **High** network **traffic** (high number of forwarders) ✔
- **Limited hardware** of nodes

  (limited to **MCR packets in parallel** at receiver, above that packets are **ignored**) ✔

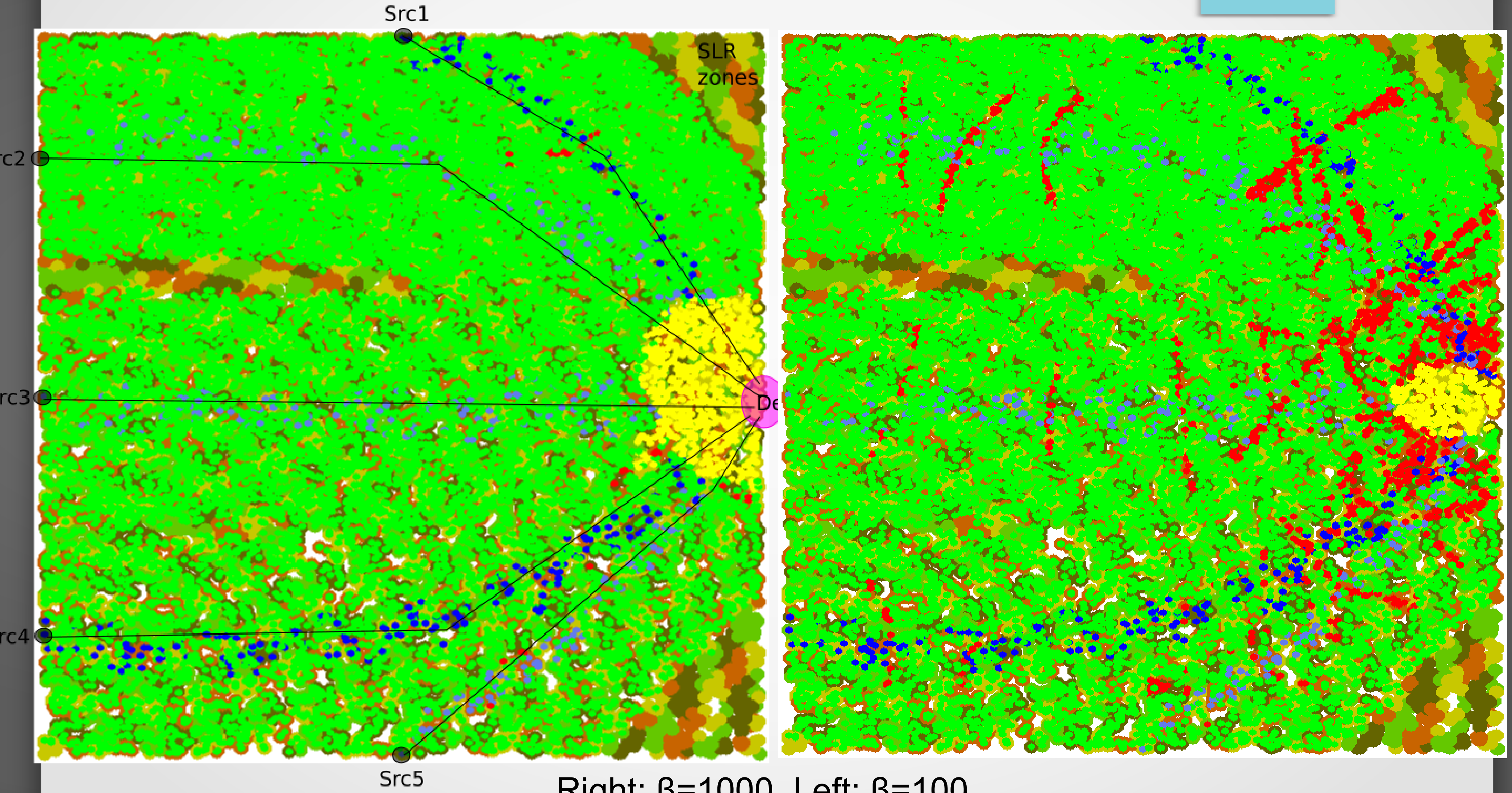
β and congestion

- Simulator: **BitSimulator**
- **5 source-destination pairs**/ 5 CBR flows of **100 packets each**
- Nanonetwork
  - **Heterogeneous**:
    - 10000 nodes upper band
    - 6000 nodes middle band
    - 4000 nodes bottom band.

Parameter	Value
Size of simulated area	6 mm * 6 mm
Number of nodes	20 000
Communication range	900 µm
Data packet size	1000 bit
Number of flows	5
Number of packets per flow	100
Routing protocol	SLR backoff
Communication range for SLR addressing phase	250 µm
Backoff redundancy	20
MCR	3
Pulse duration T_p	100 fs
MaxBitError	0

Scenario Parameters

β and congestion: Simulation results



Right: β=1000. Left: β=100.
Source inter-packet interval=100 μs.

β and congestion: Simulation results

Effect of β and source packet rate on **ignore and collision:**

- **Lower β → Lower Ts**
  - → **Faster symbol processing**

    → Faster packet quitting buffers

    → **Lower ignore.**
  - → **Higher overlapping** probability of symbols of multiple packets

    → **Higher collision**.
- **Higher source rate → Higher traffic**
  - → **Higher ignore.**
  - → **Higher collision.**

β and congestion: Simulation results

Effect of β and source packet rate on **packet delivery**:

- β/source rate pair → **high ignore** → **packet loss**.
- **High collision** is more **tolerated** than high ignore: altered packets on route, but **others** arrive **successfully** to destination(s).

β and congestion: Simulation results

Effect of **dynamic** β**:**

- **Modulations:**
  - **TS-OOK**: fixed β= 1000 for all nodes.
  - **RD TS-OOK**: **dynamic co-prime β** for transmitters, randomly from 1009, 1013 and 1019.
- **Results:**
  - **Similar ignores and collisions**, as β close.
  - **However,** with **error correction codes**

    → **RD TS-OOK** has **fewer collisions** than TS-OOK (**fewer bit errors/packet**).

β and congestion: Conclusion

- **IoT** and **IoNT** → Connecting devices **densely** → **Scalability**.
- **Nanonetworks**: undiscovered and **exciting** topic of research.
- If **congestion** is **detected** in nanonetwork, verify β and source rate:
  - **Lower source rate** (if application allows it): source sends then pauses then sends then pauses etc.
  - **Lower β** (if nanomachine allows it) → less buffer overflow → good packet delivery, even with high collisions on route.

Final Word

Thanks