INTERNET OF THINGS:
TRENDS, DIRECTIONS, OPPORTUNITIES, CHALLENGES

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http://www.ece.gatech.edu/research/labs/bwn
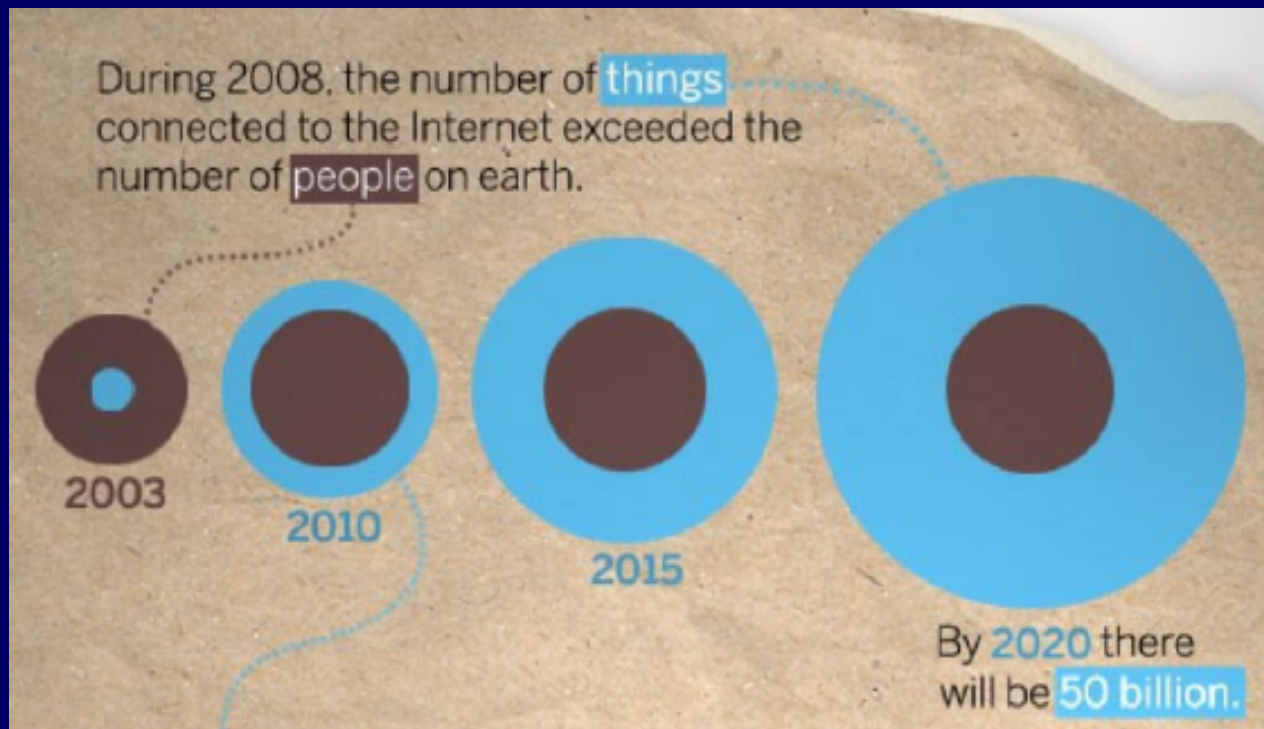
What is the Internet of Things?

Internet connects all people ➔ **"Internet of People"**
IoT connects all things ➔ **"Internet of Things"**

Interconnection of Things or Objects or Machines,
e.g., sensors, actuators, mobile phones, electronic devices, home
appliances, any existing items
and interact with each other via Internet.

INTERNET OF THINGS GROWTH

During 2008, the number of things connected to the Internet exceeded the number of people on earth.

2003

2010

2015

By 2020 there will be 50 billion.

Connection of
7 Billion of People and
7 Trillion Things

MAJOR CHARACTERISTICS

- **Very Large Scale**

- **Heterogeneity**

- **Pervasivity**

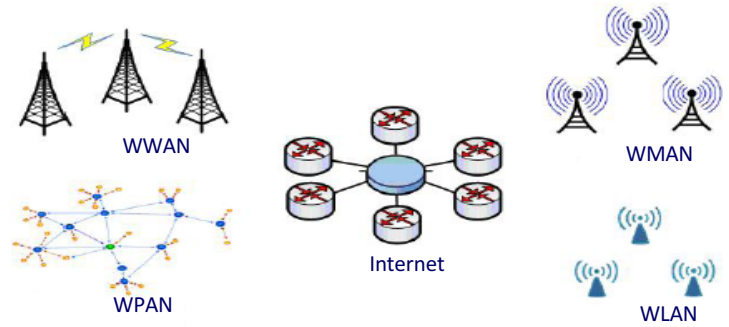 Computing and communication technologies will be embedded in our environments
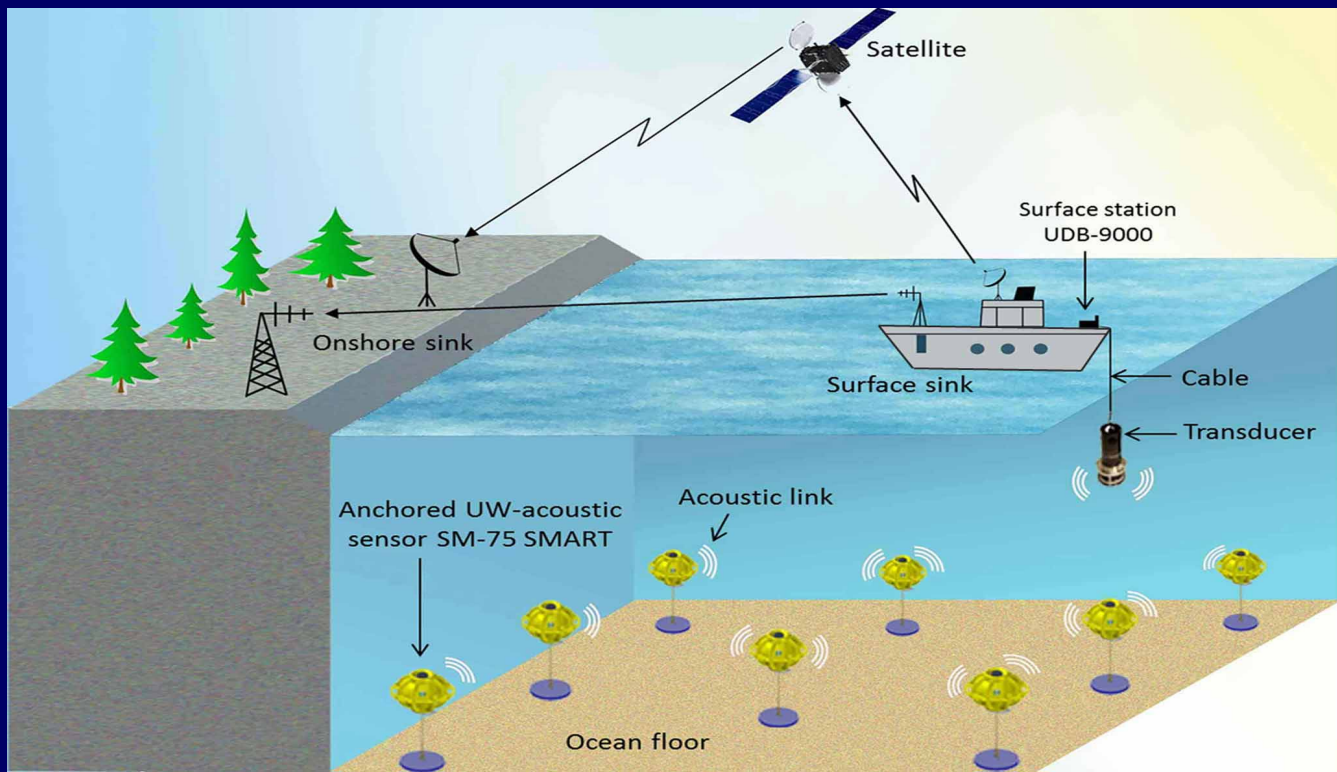
4 Layers Model of IoT

Integrated Application

Smart Logistic	Smart Grid	Green Building	Smart Transport	Env. Monitor

Information Processing

Data Center	Search Engine	Smart Decision	Info. Security	Data Mining

Network Construction

WWAN

WMAN

WPAN

Internet

WLAN

Sensing and Identification

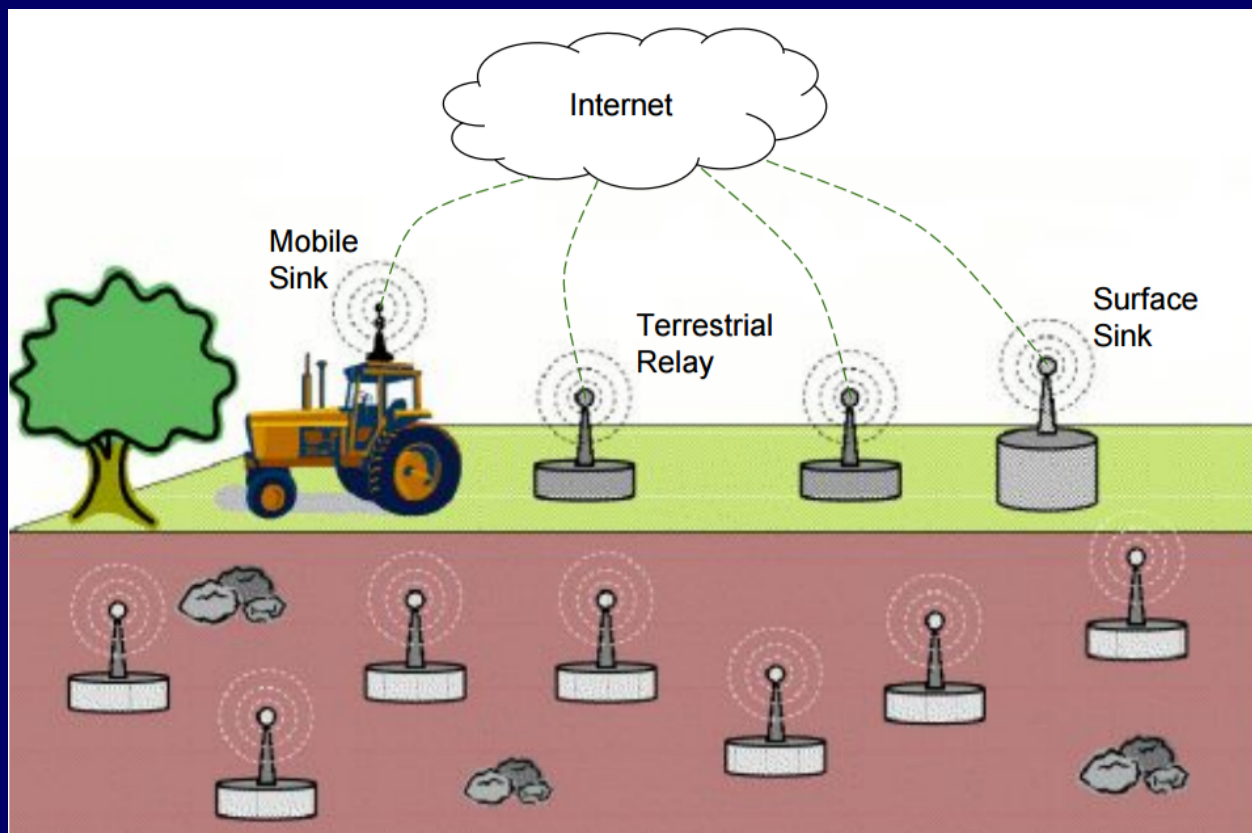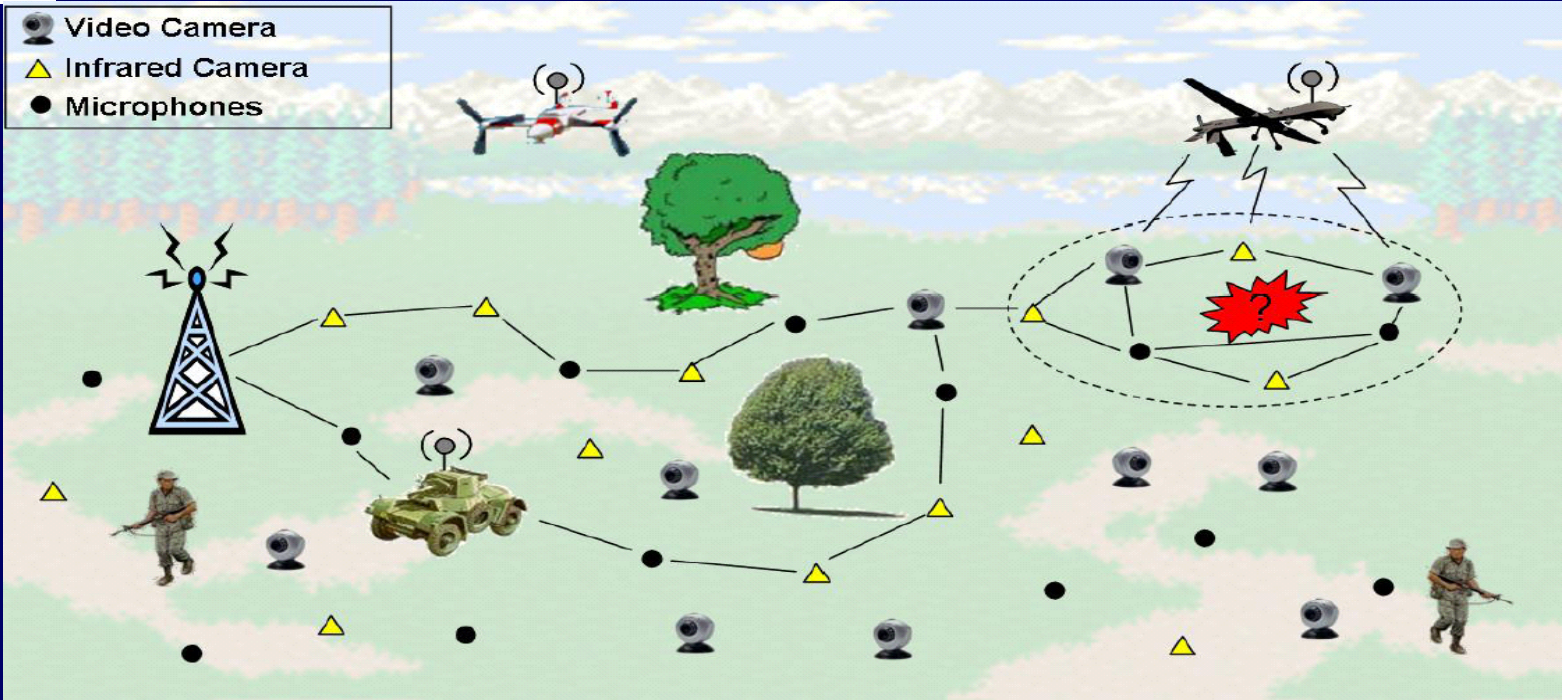|				
GPS	Smart Device	RFID	Sensor	Sensor

INTERNET OF UNDERWATER THINGS
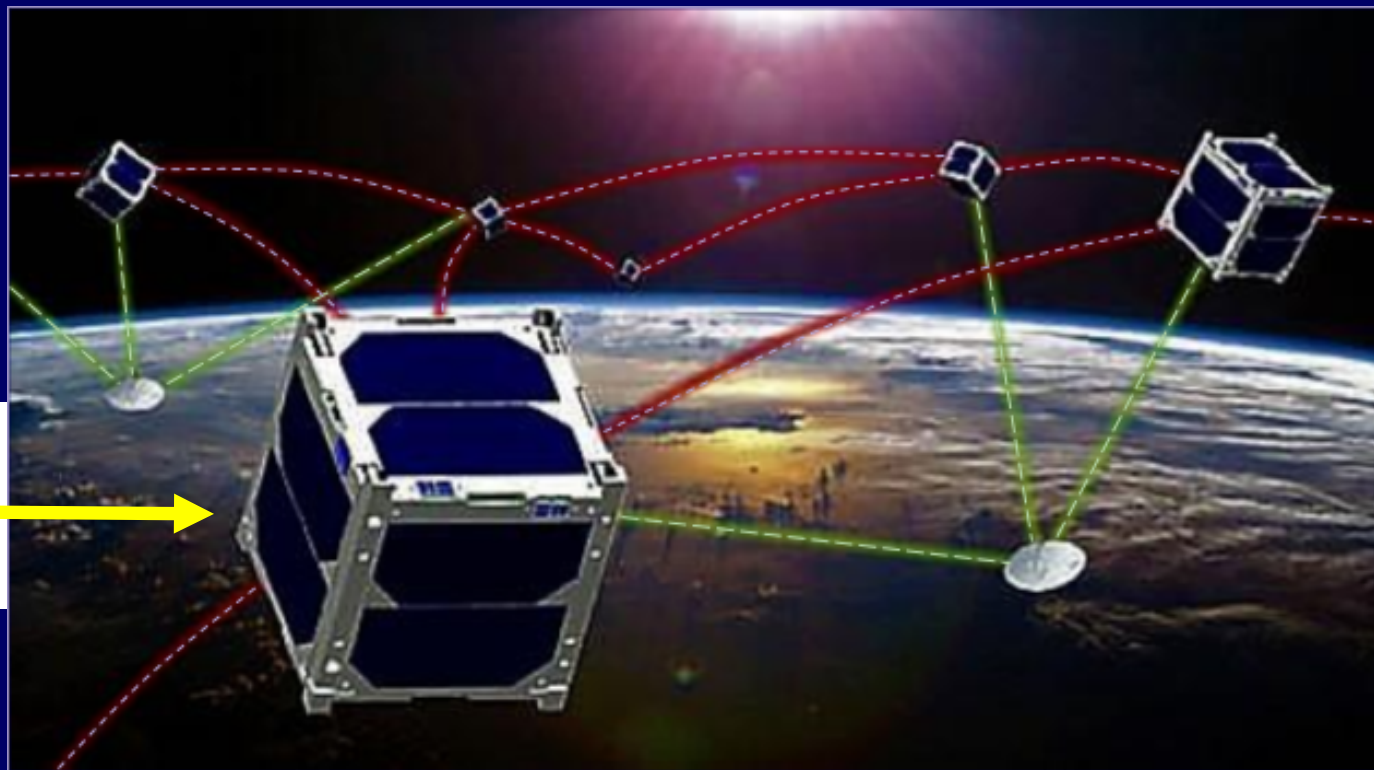
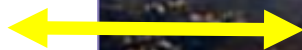# INTERNET OF UNDERGROUND THINGS

Internet of Battlefield Things

INTERNET OF SPACE THINGS
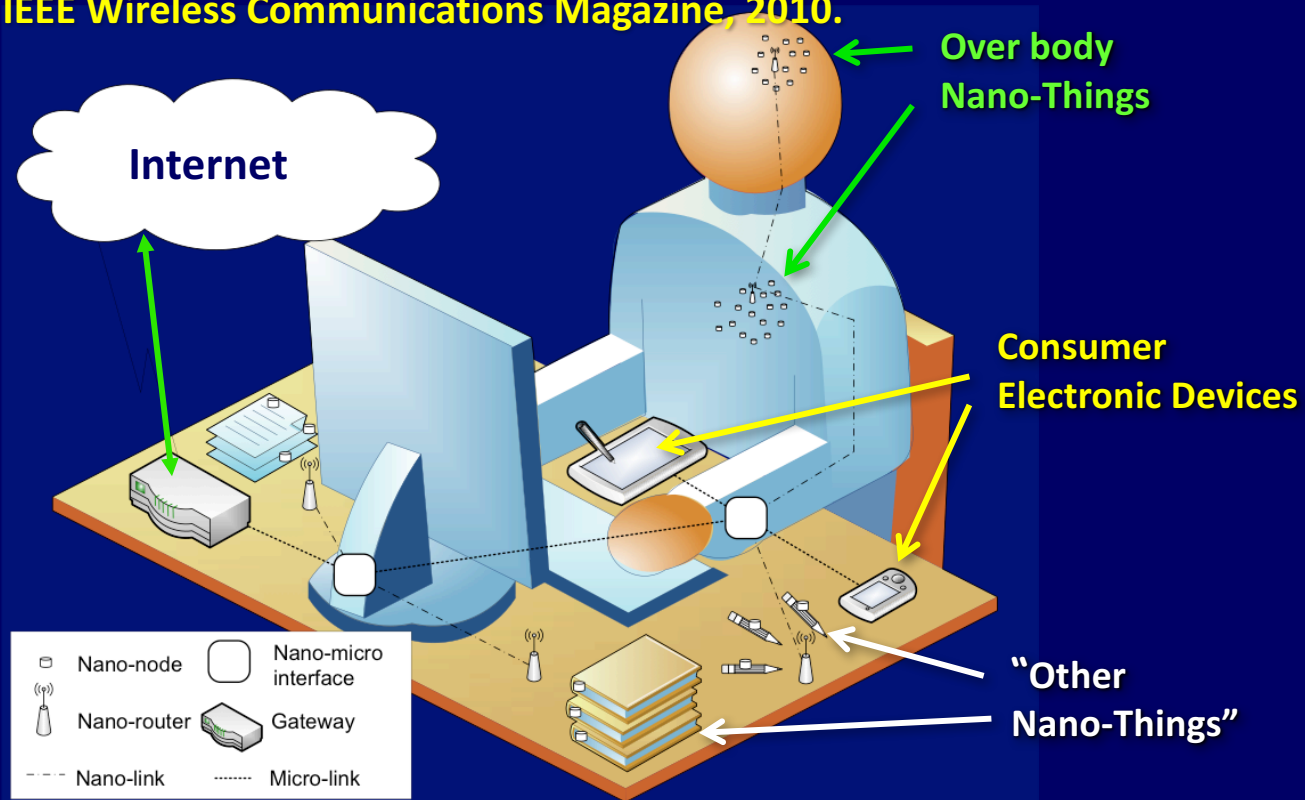

Coffee mug size
Satellites

Univ of New Mexico

INTERNET OF NANOTHINGS

I. F. Akyildiz and J. M. Jornet,
"The Internet of Nano-Things,"
IEEE Wireless Communications Magazine, 2010.

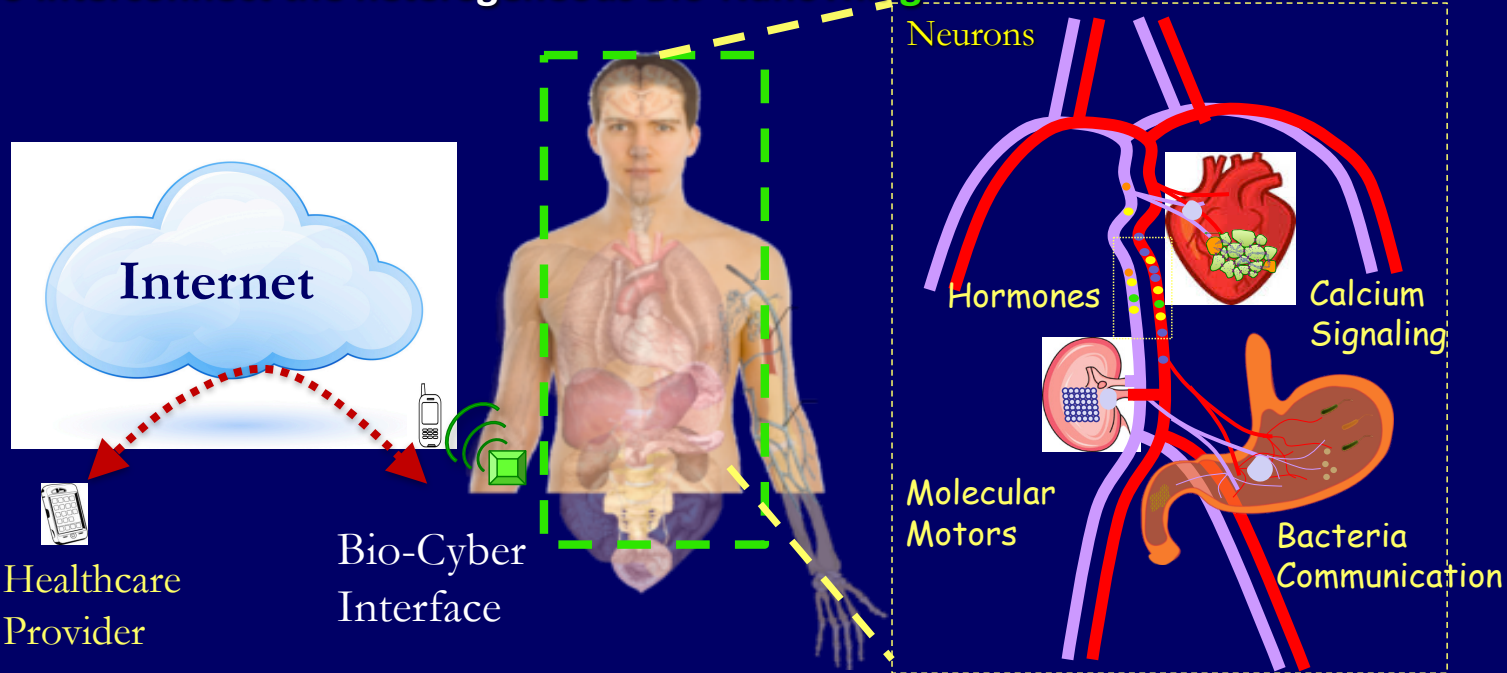# INTERNET OF BIO-NANOTHINGS

**I.F. AKYILDIZ, M. PIEROBON, S. BALASUBRAMANIAM, Y. KOUCHERYAVY,
"THE INTERNET OF BIO-NANOTHINGS",
IEEE COMMUNICATIONS MAGAZINE, MARCH 2015**

Objective:

To interconnect the heterogeneous Bio-NanoThing Networks to the Internet

Internet

Healthcare Provider

Bio-Cyber Interface

Neurons

Hormones

Calcium Signaling

Molecular Motors

Bacteria Communication

INTERNET OF THINGS: PERSPECTIVE

Any TIME

- On the Move
- Outdoors and Indoors
- Nights and Daytime

- Outdoors
- Indoors
- On the Move

Any PLACE

- Human to Human (H2H)
- Human to Thing (H2T)
- Thing to Thing (T2T)

Any THING
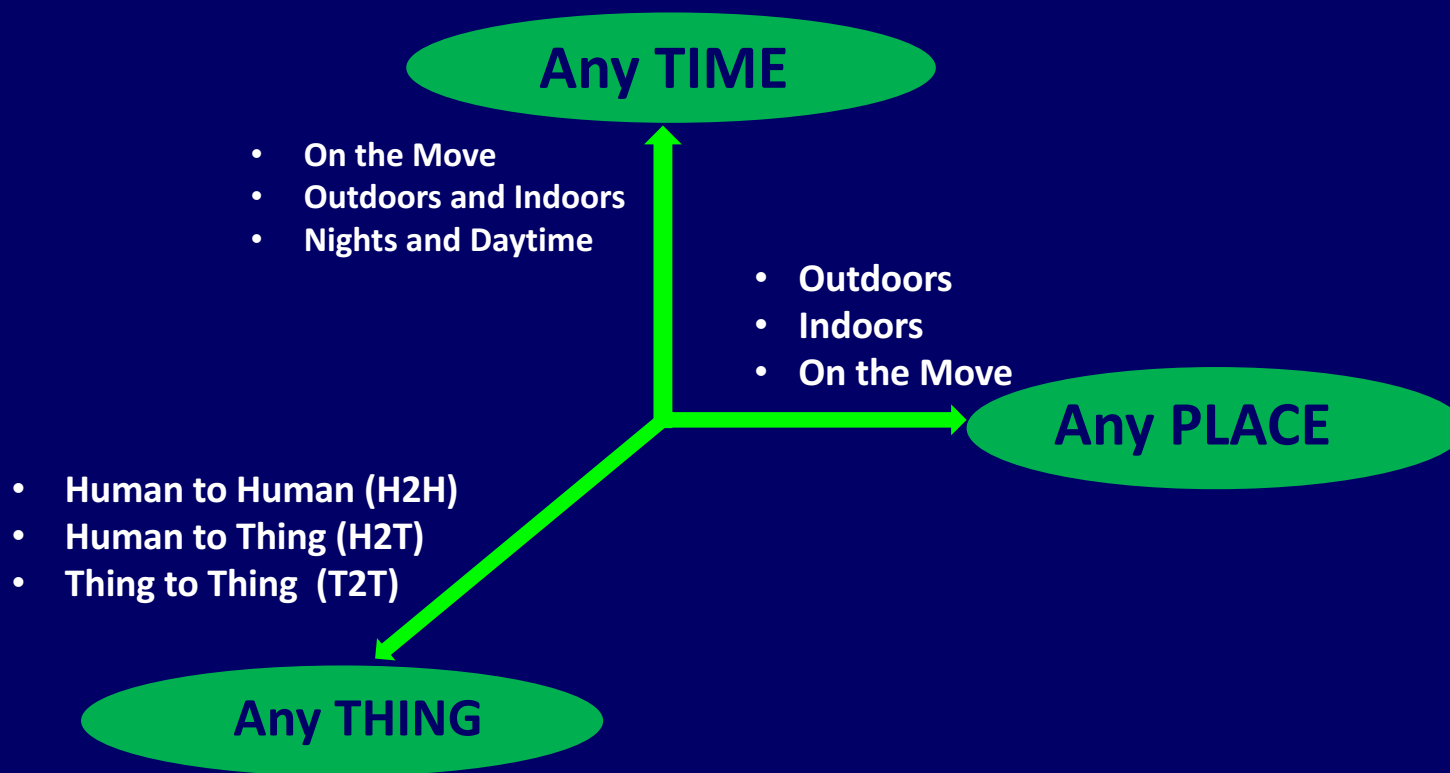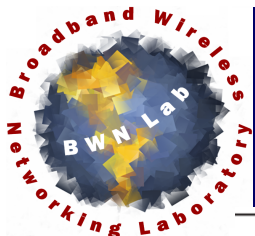
TOP INDUSTRIES KEY FOR IoT APPLICATIONS DEVELOPMENT AND REVENUE GENERATION
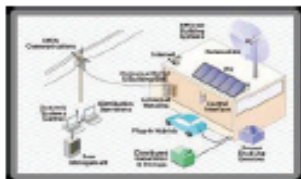
Smart Grid

Smart Health

Smart Home

Smart Cities

Smart Industries

Smart TV

Smart Watch

Smart Car

Smart Kegs

Automative & Transportation

NEST Thermostat	Corventis: Wireless Cardiac Monitor	WEMO Remote	Tractive Pet Tracker
Ninja Blocks	Revolve Home Automation	ThingWorx Application Platform	Lings Cloud Platform
Mbed Development Platform	Xively Remote Access API	Intel Quark Processor	AllJoyn S/W Framework

IoT PLATFORMS ON THE MARKET

- **GE Predix**

- **Cisco IoT Cloud**

- **IBM Watson IoT**

- **PTC ThingWorx**

GE PREDIX

- **Uses a platform as a service (PaaS) model and is a cloud-based OS**

- **Built on Cloud Foundry, an open-source platform, and is optimized for secure connectivity and analytics at scale, both in the cloud and on the edge**

CISCO IoT CLOUD

■ **Designed around six pillars of technology:**

  – **Network connectivity**

  – **Fog computing**

  – **Data analytics**

  – **Security (cyber and physical),**

  – **Management/automation, and**

  – **Application enablement.**

Cloud addresses challenges across a wide variety of industries, including manufacturing, utilities, oil and gas, transportation, mining, and the public sector.

IBM WATSON IoT

Cloud Foundry, Docker®, OpenStack®, Watson IoT Platform development

Platform connects sensors to cloud applications using IBM Bluemix®

PTC® THINGWORX®

■ **Three pillars of technology:**

- **Core application enablement**
- **Connection services with device and cloud adopters, and**
- **Edge connectivity using the Edge MicroServer and Edge "Always On" devices**

(27% market share)

APPLICATION OF IoT: SMART HOME

- **Remote Monitoring/Control (Appliances)**

- **Safety:**
  When do the doors open/close?

- **Energy Management:**
  Turn off the lights/AC?

- **Maintenance:**
  Are the sinks/pipes leaking?

- **Entertainment Control**

ADOPTION OF IoT NETWORKS: HEALTHCARE INDUSTRY

The global IoT healthcare market is expected to grow from $32.47 billion in 2015 to $163.24 billion by 2020:

- Remote patient monitoring services
- Mobile health technology
- Telemedicine
- Medication Management
- Improved Clinical Care
- Employee workflow management and
- Inpatient monitoring

Adoption of IoT Networks: Transportation

- **Save lives and property**
- **Reduce emissions and**
- **Cut commuting time and effort**

SAFETY

1.3 million dead 2013
2.4 million to die 2030

ROADSIDE INSTALLATIONS

SENSORS FOR DATA COLLECTION

EFFICIENCY

EU annual congestion
cost 130 billion euro.

LANES SHIFT RIGHT

COMMUNICATION

SUSTAINABILITY

Road transport 20% of
EU total CO_2 emission
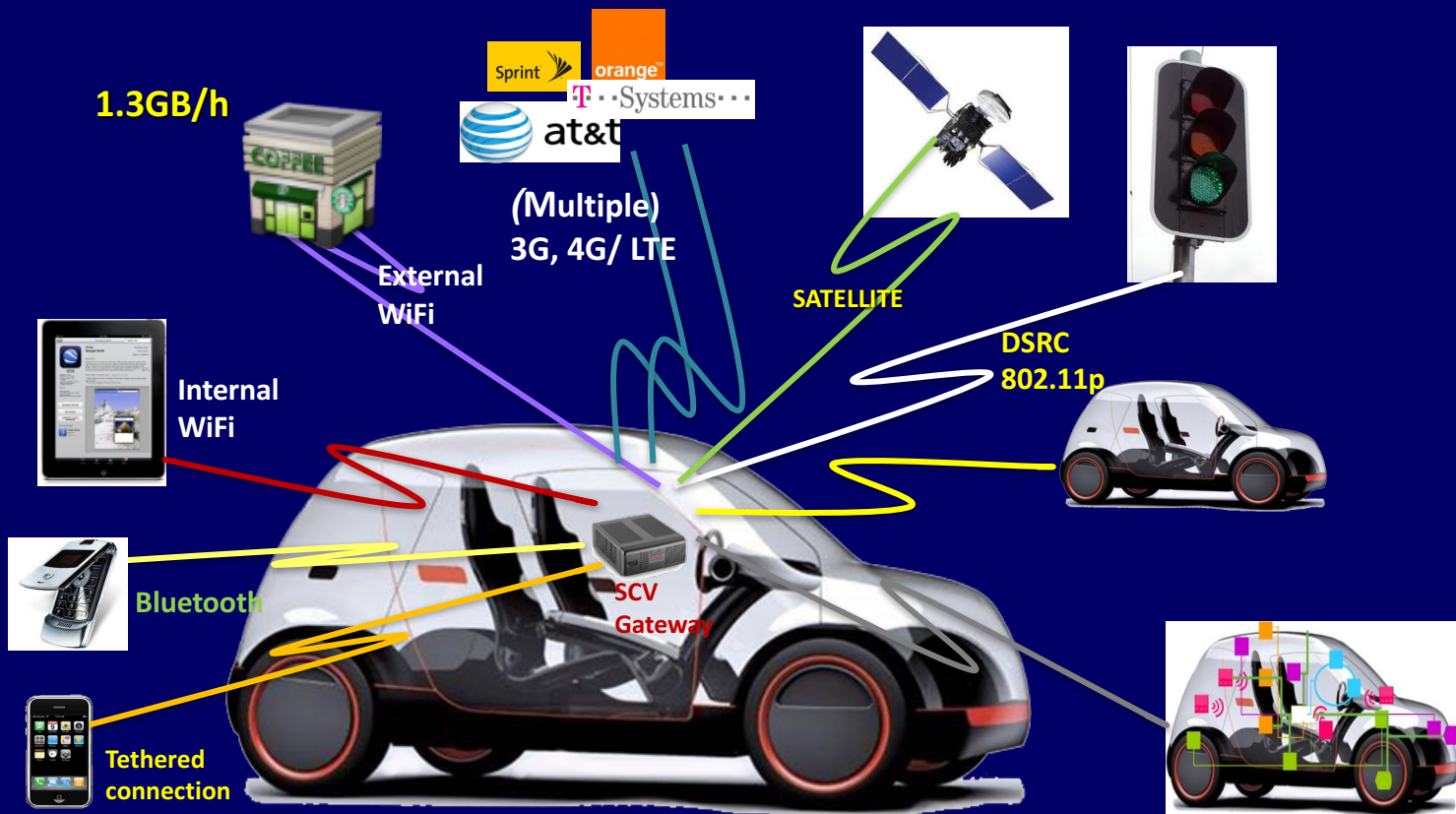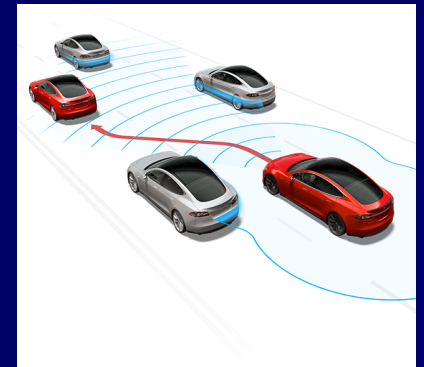
TRAFFIC MANAGEMENT

Adoption of IoT Networks: Transportation

Intelligent Transportation

- **Driver warning, autopilot, emergency self stop, traffic management**

- **Real-time vehicle tracking and fleet management**
- **Route planning information, high-precision estimated arrival times**
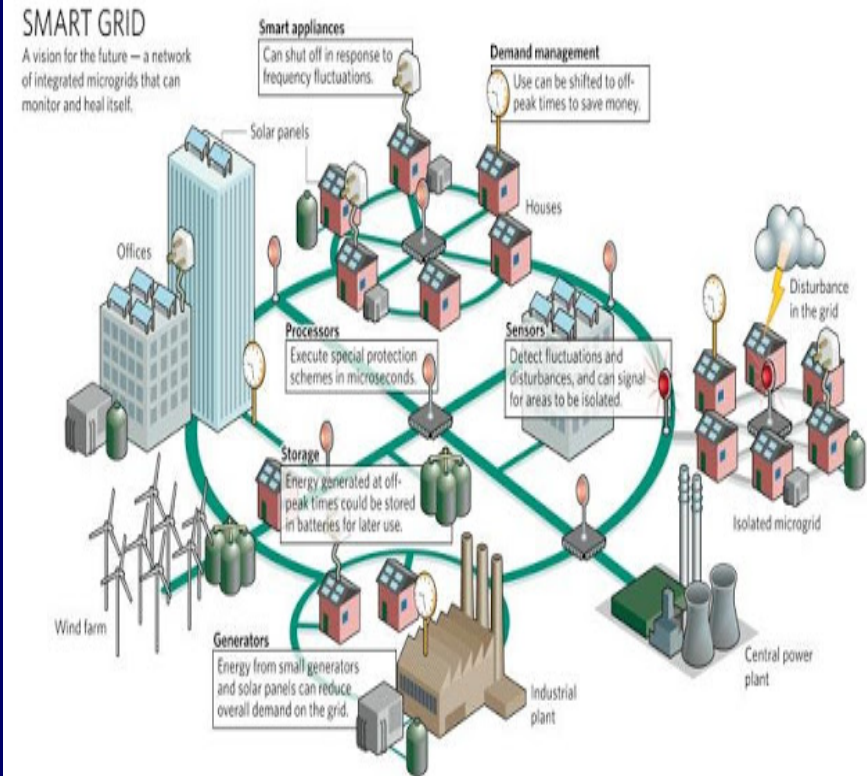- **Valuable data for insurance companies**

ADOPTION OF IoT NETWORKS: SMART GRID

Utility companies use IoT to improve

* asset performance
* reduce costs
* infrastructure management,
* lower supply chain risks and
* empower employees and consumers
* More efficient and proactive maintenance

**By the end of 2017, annual smart grid spending
in China could total $20 billion,
with smart meters comprising
$2 billion of that total**

SMART GRID
A vision for the future — a network of integrated microgrids that can monitor and heal itself.

Smart appliances
Can shut off in response to frequency fluctuations.

Demand management
Use can be shifted to off-peak times to save money.

Solar panels

Houses

Offices

Disturbance in the grid

Processors
Execute special protection schemes in microseconds.

Sensors
Detect fluctuations and disturbances, and can signal for areas to be isolated.

Storage
Energy generated at off-peak times could be stored in batteries for later use.

Isolated microgrid

Wind farm

Generators
Energy from small generators and solar panels can reduce overall demand on the grid.

Industrial plant

Central power plant

TRENDS IN SPENDING FOR IoT SOLUTIONS

Worldwide IoT market will grow from $655.8 B/2014 to $1.7 T/2020 with a compound annual growth rate of 16.9%.

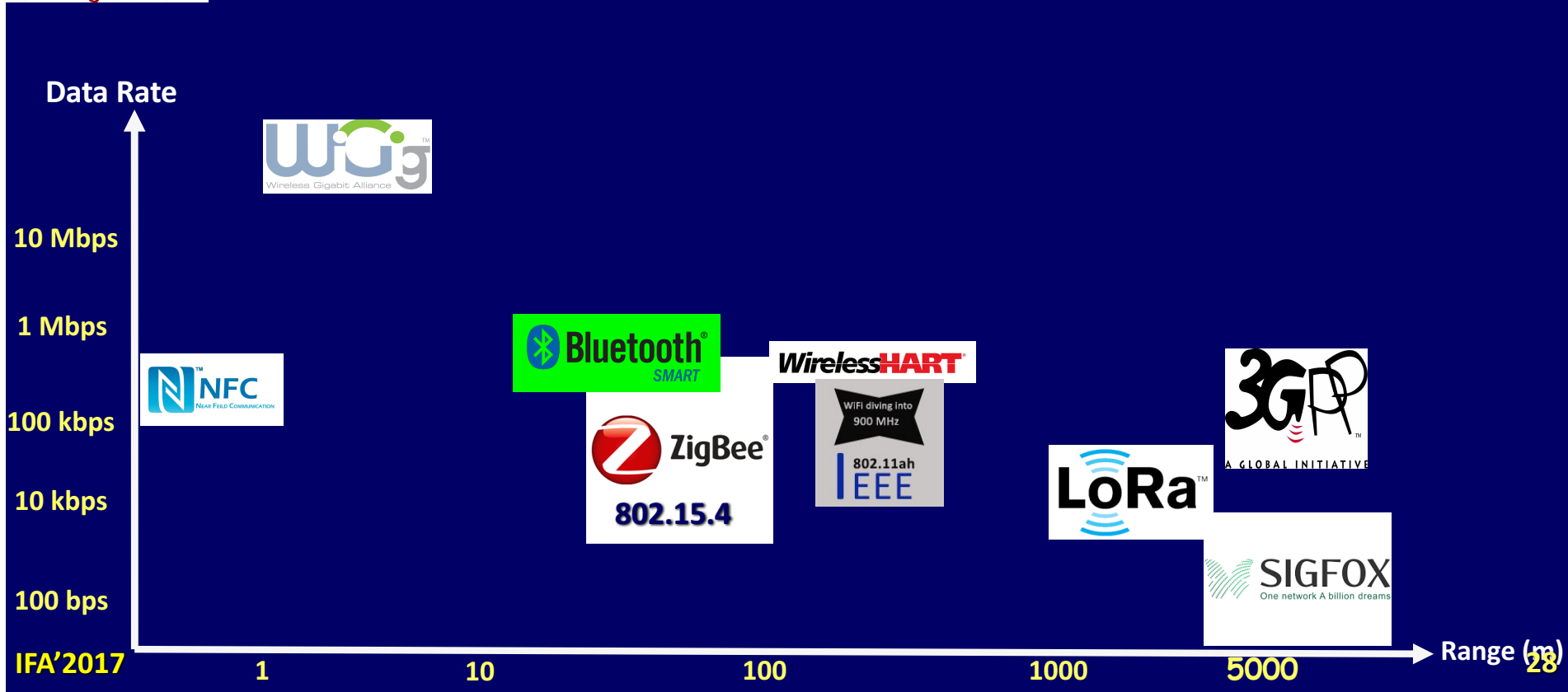IoT analytics market is estimated to grow at a CAGR of 27.48% from 2015 to 2020 to reach $ 16.35 B by 2020.

Total service spending (including professional, consumer and connectivity services) will reach $482 billion in 2020, growing at a 21% CAGR from 2013.

IoT market in manufacturing operations will grow from $42.2B/2013 to $98.8B/2018

Global spending on retail IoT initiatives is expected to grow from $14.3 B/2015 to $35 B/2020.

IoT CONNECTIVITY COMPETITIVE LANDSCAPE

Data Rate (vertical axis): 10 Mbps, 1 Mbps, 100 kbps, 10 kbps, 100 bps

Range (m) (horizontal axis): 1, 10, 100, 1000, 5000

Technologies plotted: WiGig, NFC, Bluetooth SMART, ZigBee 802.15.4, WirelessHART, WiFi diving into 900 MHz 802.11ah IEEE, LoRa, 3GPP A GLOBAL INITIATIVE, SIGFOX One network A billion dreams

Broadband Wireless Networking Laboratory — BWN Lab

IFA'2017

28

eMTC — Category M device for LTE

NB-IoT — Narrowband IoT

EC-GSM — Extended Coverage GSM

Release 13
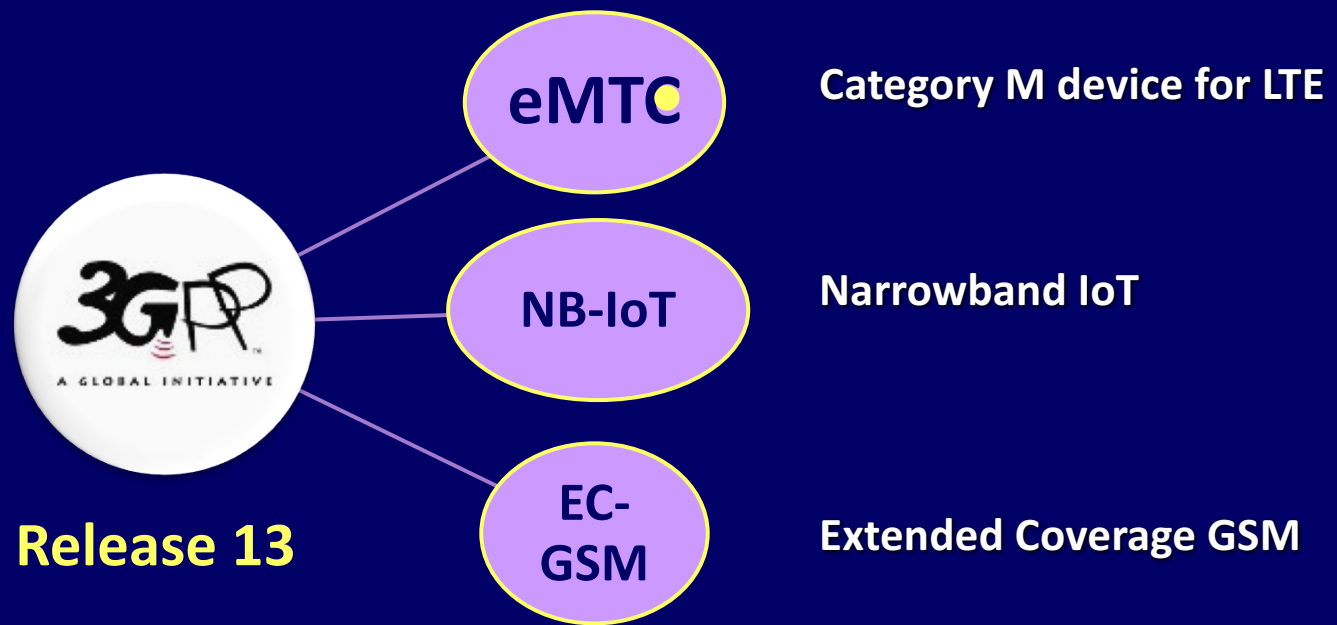
SCALING TO CONNECT THE INTERNET OF THINGS

Scaling up in performance and mobility ←

Scaling down in complexity and power →

LTE Advanced
> 10 Mbps
n x 20 MHz

LTE Cat-1
Up to 10 Mbps
20 MHz

eMTC (Cat-M1)
Up to 1 Mbps
1.4 MHz narrowband

NB-IoT (Cat-M2)
10s of kbps to 100s of kbps
180 kHz narrowband

LTE Advanced (Today+)

LTE IoT (Release 13+)

Connected Healthcare

Mobile

Object Tracking

Video Security

Environment Monitoring

Wearables

Smart Buildings

Connected Car

Utility Metering

City Infrastructure

Significantly widening the range of enterprise and consumer use cases

IFA'2017

30

MAJOR OBSTACLES FOR IoT DEPLOYMENTS

- High Costs of required investment in IoT infrastructure
- Concerns about security and privacy
- Lack of senior management knowledge/commitment
- Weaknesses in organization's technology infrastructure
- Regulation (e.g., relating to data privacy)
- Weaknesses in public com infrastructure available to organization
- Immaturity of industry standard around the IoT
- General economic uncertainty
- Undeveloped consumer awareness
- Absence of business case/business model

WHAT MEASURE THE COMPANIES TAKEN TO USE THE IoT MORE EXTENSIVELY IN THE BUSINESS

- **Seeking advice from third party experts/consultants**
- **Learning from the successes or failures of early movers**
- **Training existing staff to work with the IoT**
- **Conducting or sponsoring research to establish market size/demand**
- **Establishing a cross-functional task force to explore and/or pursue IoT opportunities**
- **Introducing new business models**
- **Raising fresh capital to explore IoT options**
- **Hiring talent with IoT capabilities**
- **Establishing joint ventures or alliances to exploit IoT opportunities**
- **Establishing an IoT center of excellence**
- **Acquiring a business or assets with IoT capabilities**

IoT TRENDS TO WATCH IN THE FUTURE

■ **IT services (business consulting) → Major Driver**

■ **IoT drives demand for DATA ANALYTICS:**
   Data must be managed, integrated and analyzed

■ **IoT drives demand for CLOUD COMPUTING**

■ **IoT data → DATA BROKER**
   IoT generated data is bought, analyzed and sold
   e.g., IBM buys The Weather Company data
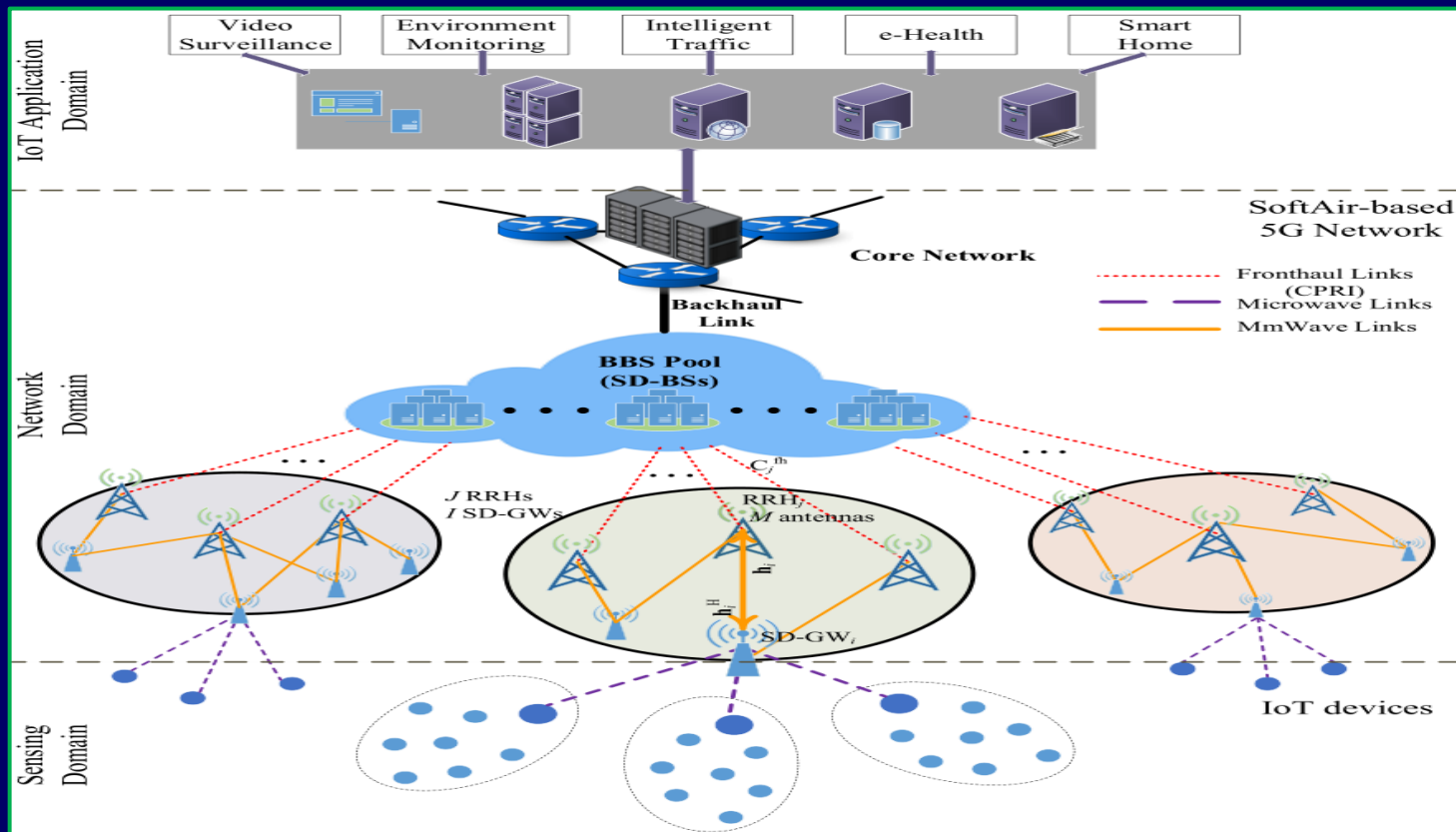
■ **Interoperability Problems**

■ **Security**

RESEARCH CHALLENGES

■ **Scalability (Massive Number of Devices)**

■ **Handle data generated by 50 billion devices**

■ **Reliable Coverage**

■ **Move cloud services to edge of the network (Fog Computing)**

■ **Reduce data to be stored (Processing and Storage)**

■ **Power Consumption Problem (Energy Harvesting; SW Optimization)**

■ **SDN/NFV Based IoT**

SDN/NFV Based IoT   (5G)

CHALLENGE: STANDARDIZATION

■ **Standardization for**

- Interoperability

- Heterogeneity of Sensors

- Interfaces to Cloud Servers