Use-cases and research opportunities of latest wireless technologies in bio-medical applications

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University of Puerto Rico at Mayaguez (UPRM)

- Puerto Rico , US territory
- Bilingual – English/Spanish
- One of the 11 campuses of the UPR system
- Known for its STEM program, specifically engineering

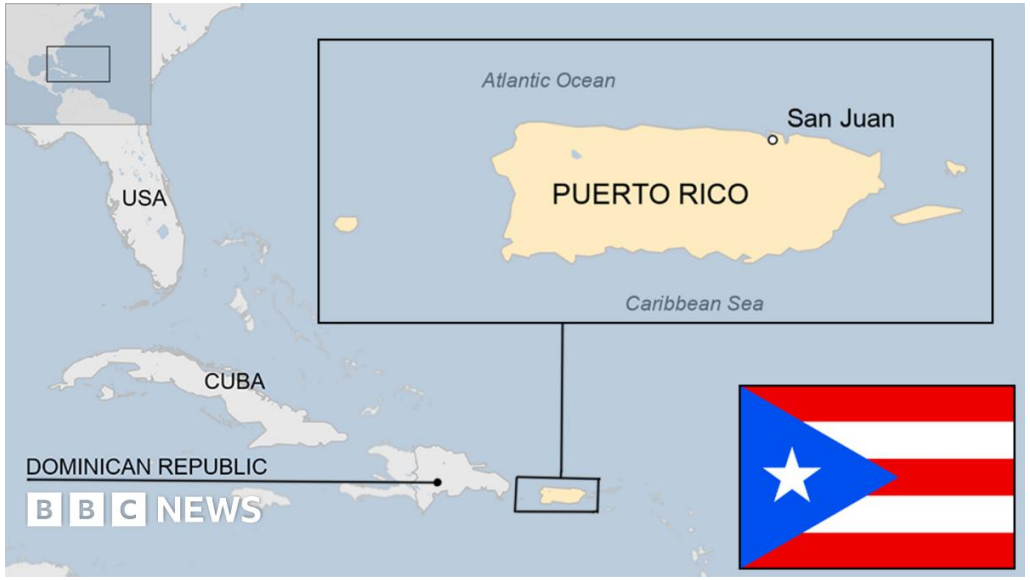


Image courtesy: Google

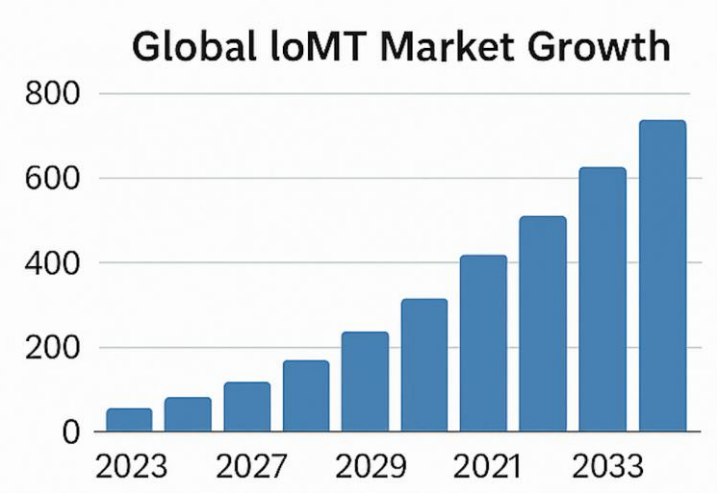
Agenda

- Motivation
- Wireless Biomedical Ecosystems (WBE)
- Challenges within WBE framework
  - Seamless IoT platform
  - Integrated spectrum sensing
  - 5G: Real-time wireless testbed
  - Cloud: Expeditious data processing
  - Cloud: Docker container-based analysis
  - Remote care: Security concerns
- Latest wireless technologies in Biomedical applications
- Conclusion

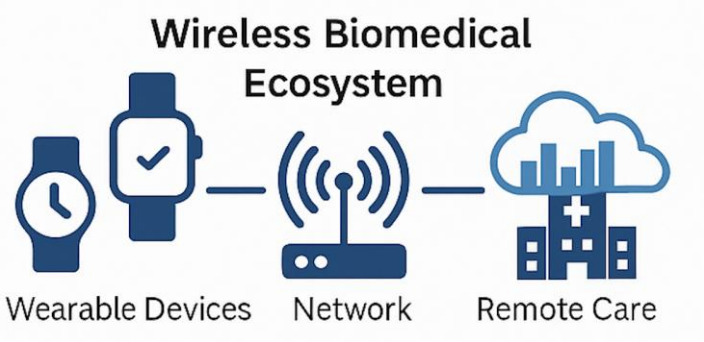
Motivation

- Rising burden of chronic diseases & demand for continuous marketing
- Explosive growth of Internet of Medical Things/ wireless health ecosystem
- Technological enablers & shift to wireless
- Challenges:
  - Interference, device reliability, energy constraints, cybersecurity, and need for autonomous operations

Wireless biomedical systems must become reliable, autonomous, and secure!



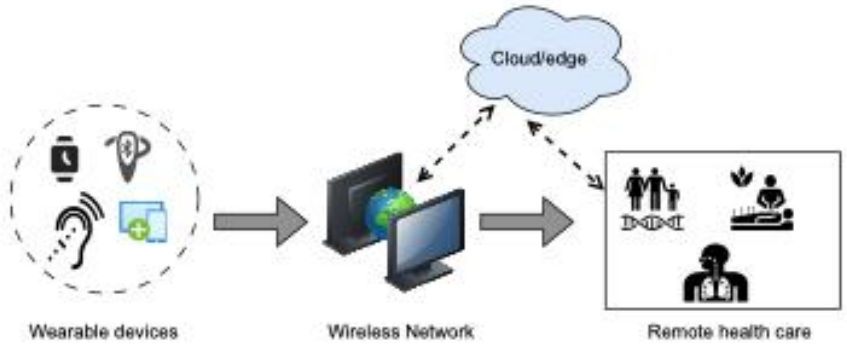
Source: Precedence research



Wireless Biomedical Ecosystem (WBE)

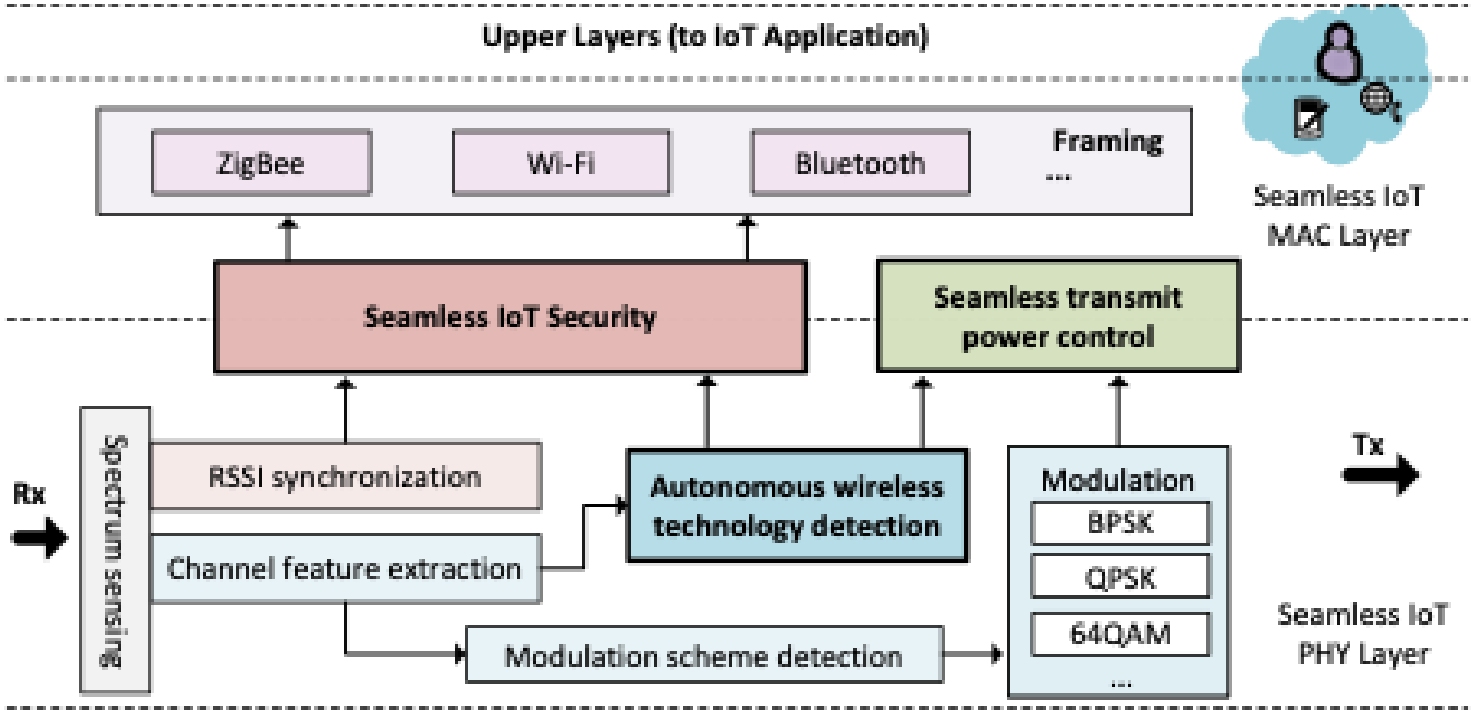
- Wearable devices - Generates biomedical signals
- Wireless network layer – Transmits data using wireless technologies such as 5G
- Edge/cloud layer – Data processing
- Remote care interface – Insights to healthcare professionals

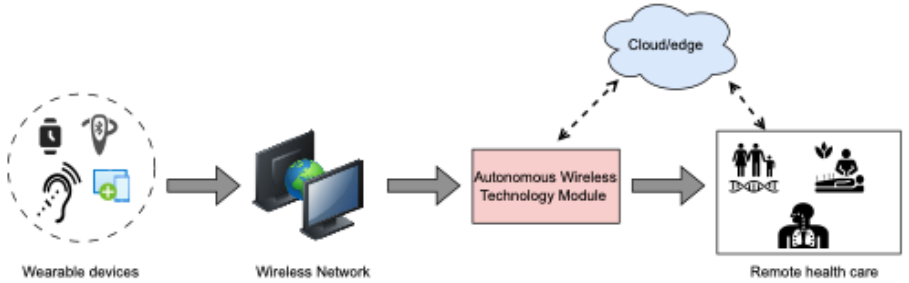
At each points within WBE, there are challenges that needs to be addressed!



Wireless biomedical ecosystem

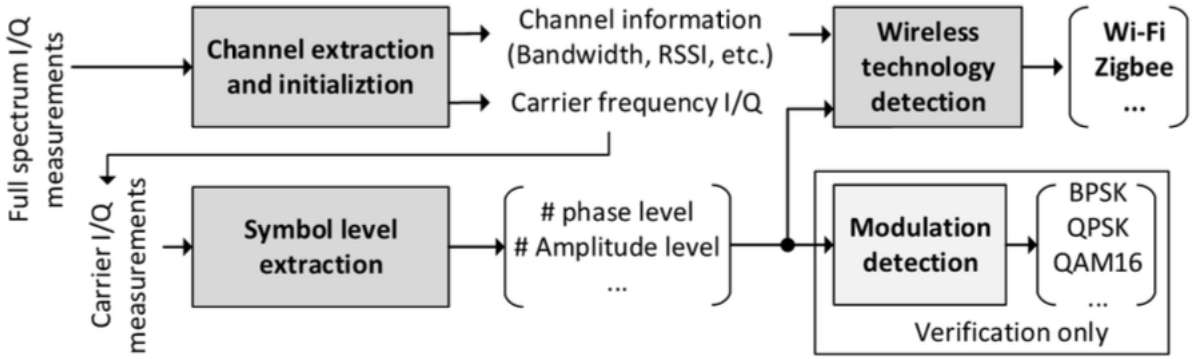
Seamless IoT Platform: Seamless, secure, and energy-efficient communication

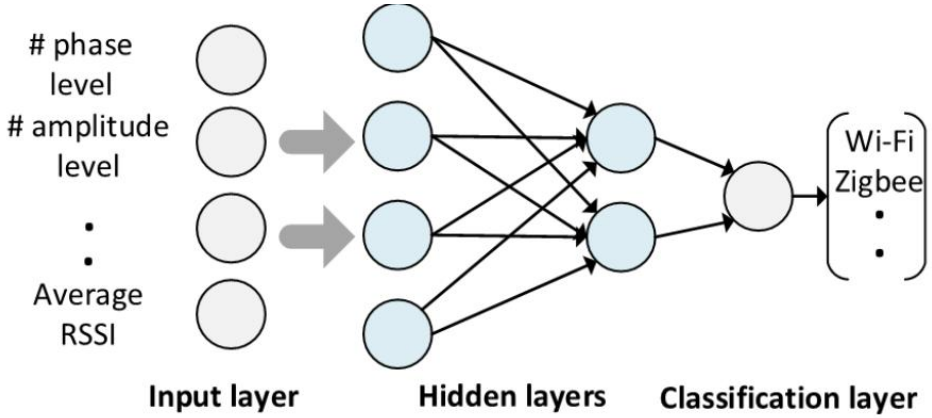


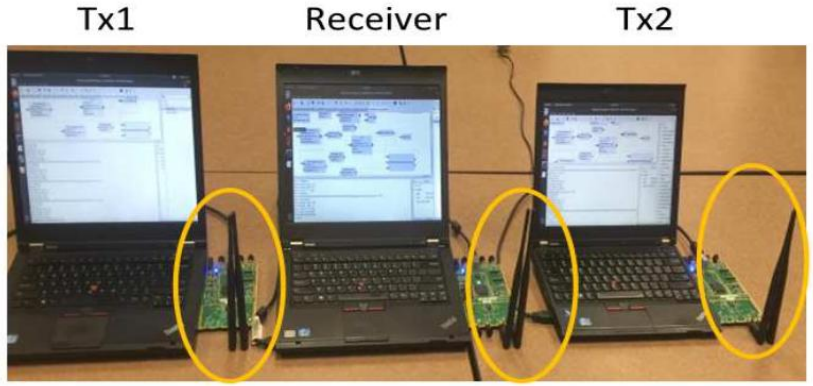


Source: Seamless IoT Platform, IEEE Communication Magazine

Seamless IoT Platform: Seamless, secure, and energy-efficient communication

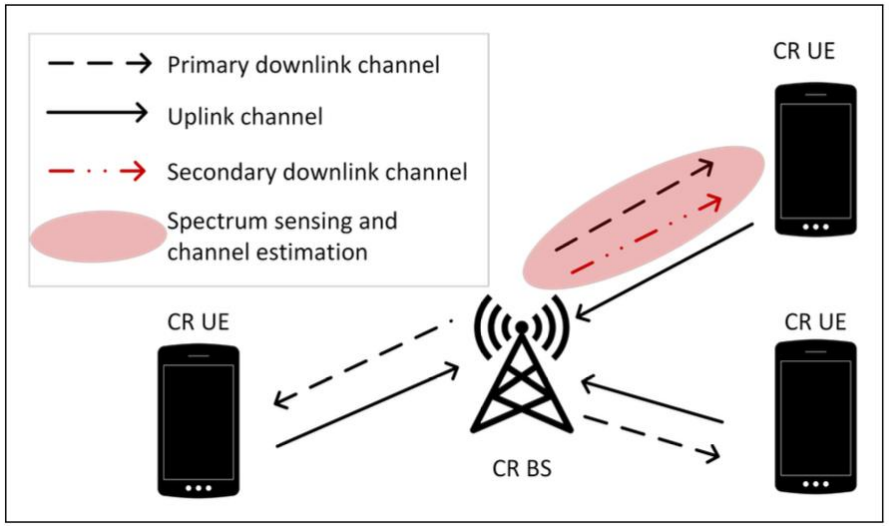


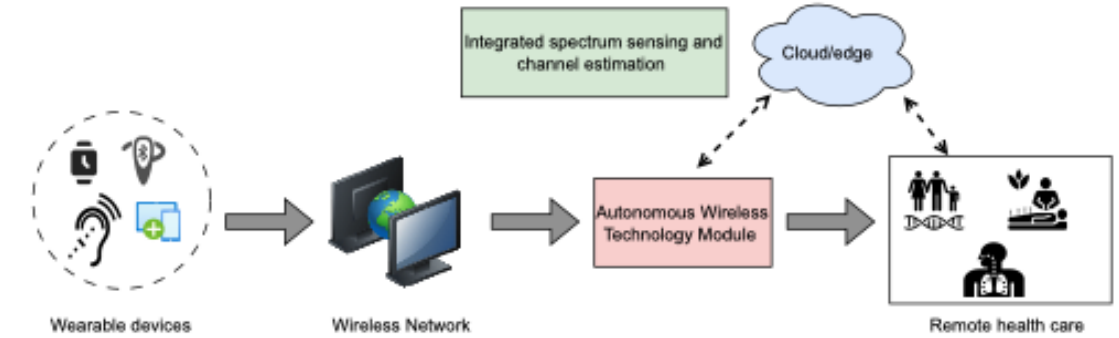


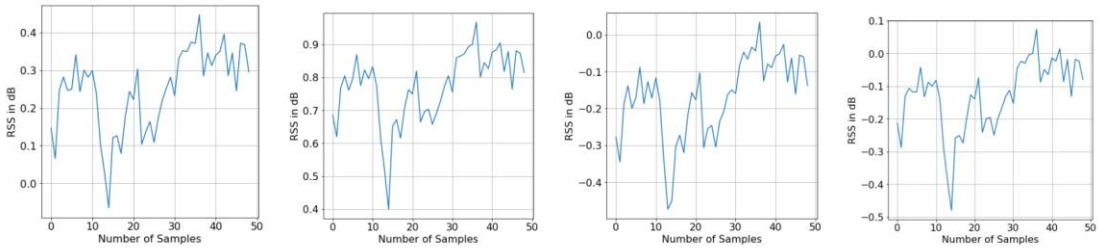


Source: Autonomous wireless technology detection, IEEE IoT journal

Cloud Systems: Integrated spectrum sensing and channel estimation

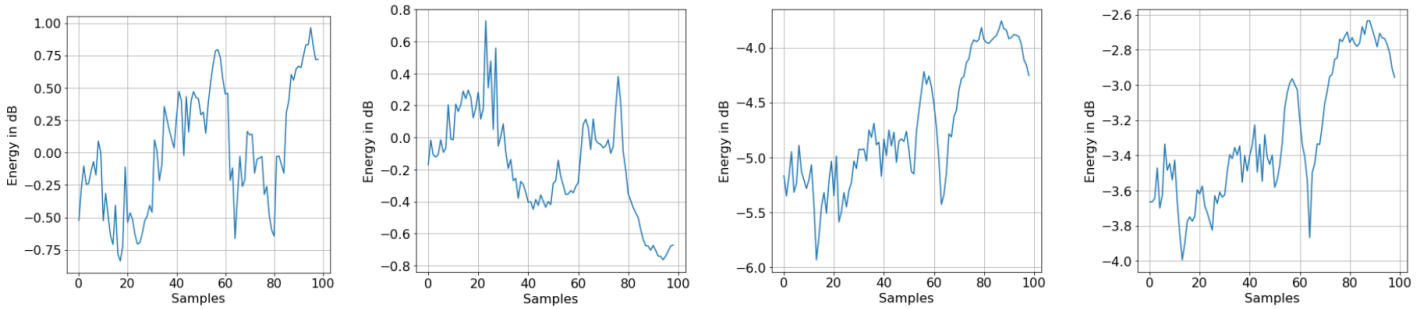






(a) Channel-1. (b) Channel-2. (c) Channel-3. (d) Channel-4.

Raw measurements

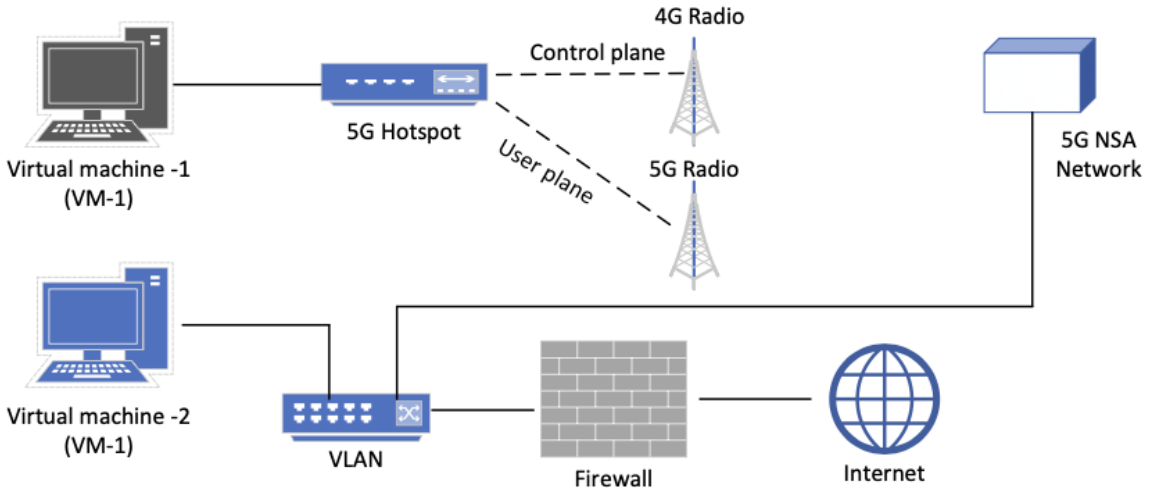


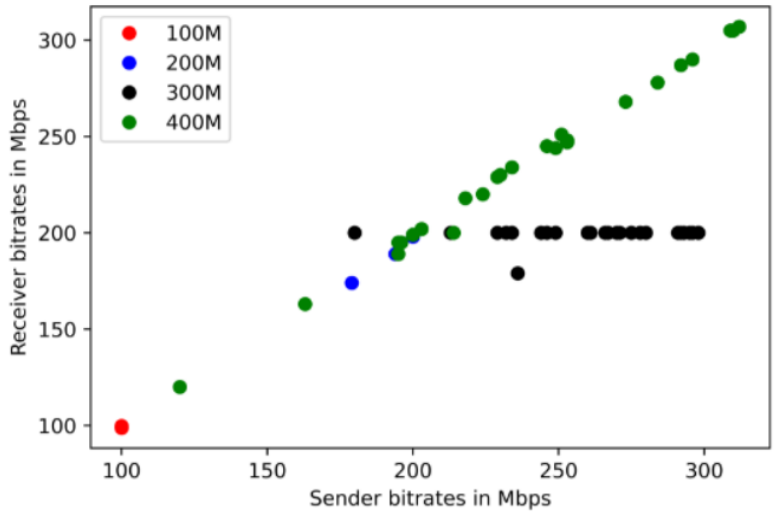
(a) Channel-1. (b) Channel-2. (c) Channel-3. (d) Channel-4.

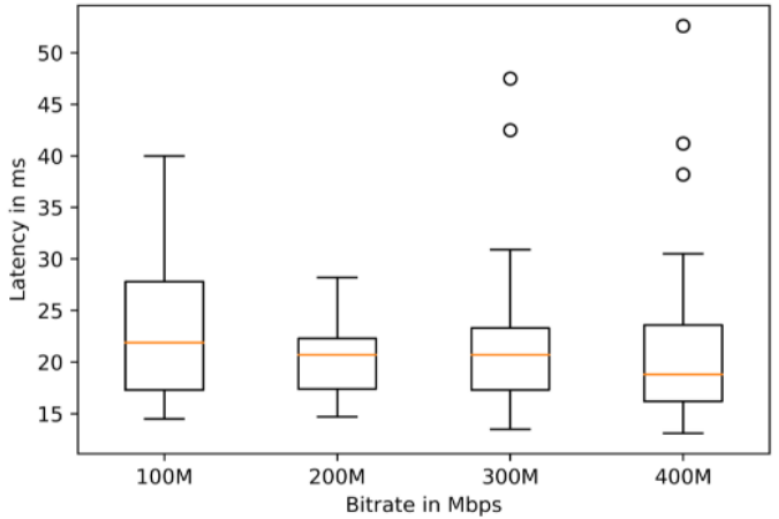
Energy levels of received signals

Source: Integrated spectrum sensing, IEEE DySpan 2024

5G: Real-time wireless testbed

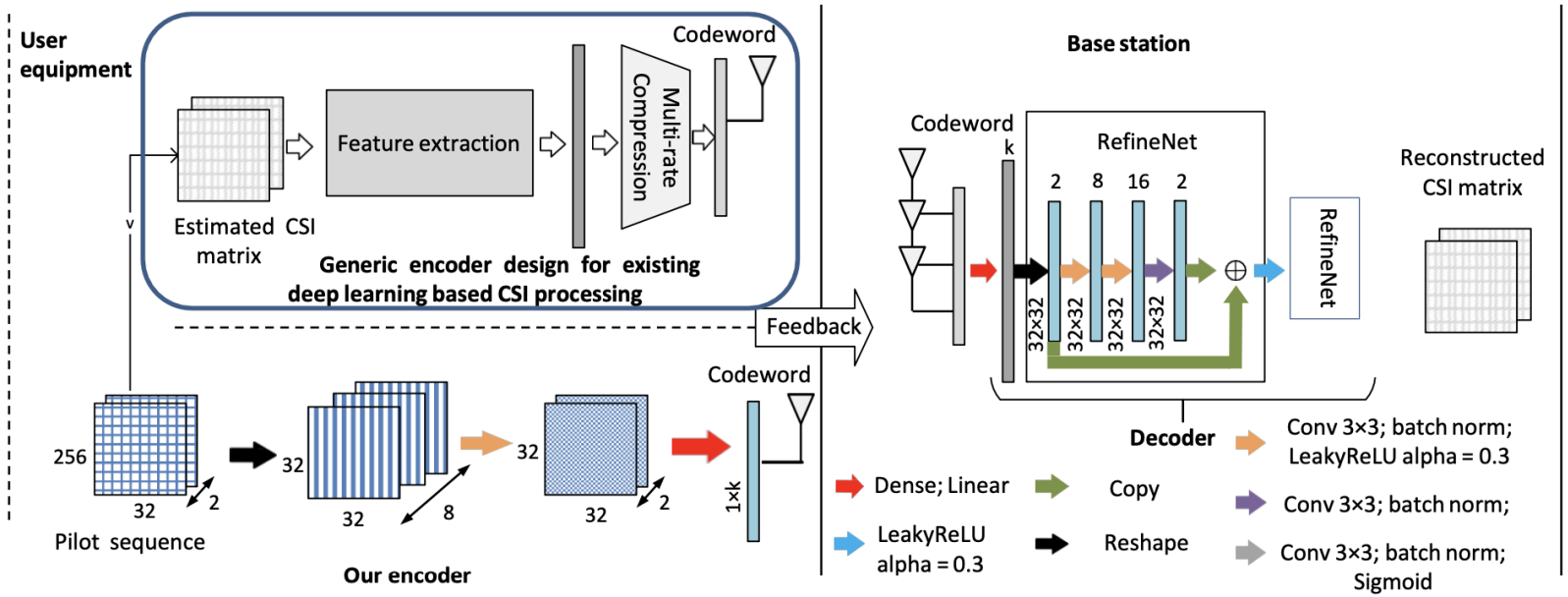




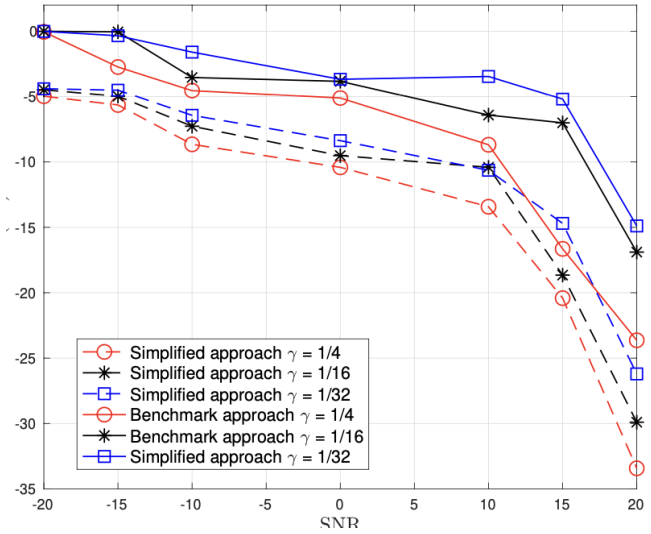


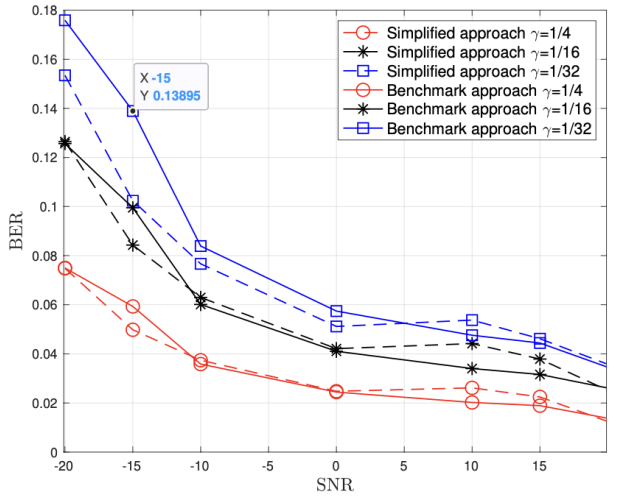
Source: Integrated spectrum sensing, IEEE DySpan 2024

Cloud: Expeditious data processing

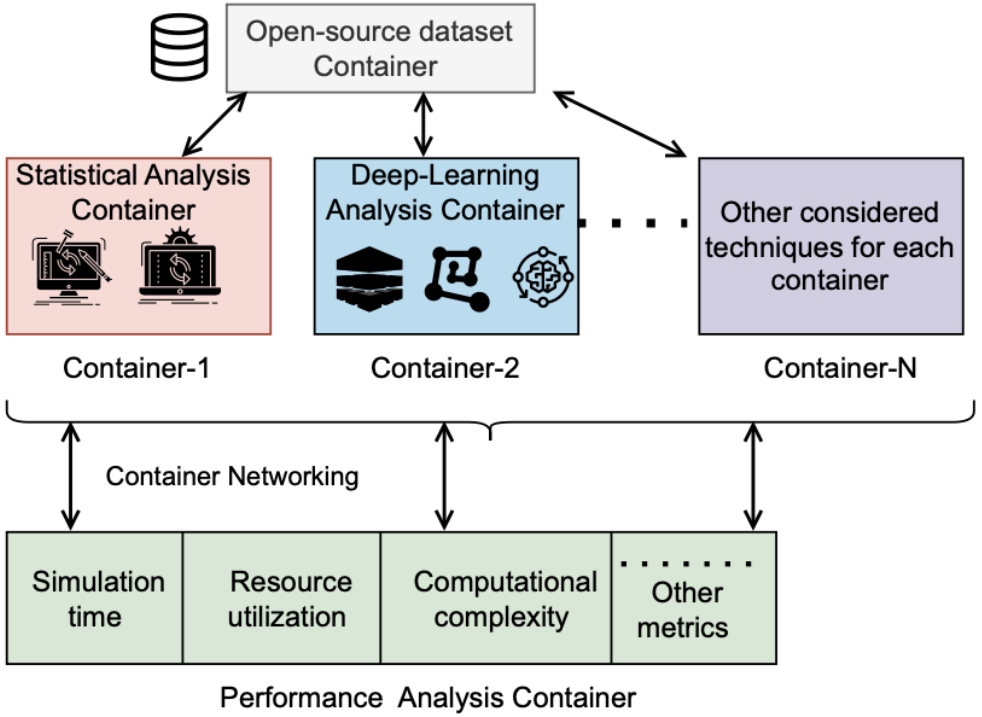


Source: Reconstructed autoencoder design, IEEE ICC 2024





Cloud: Docker container-based analysis

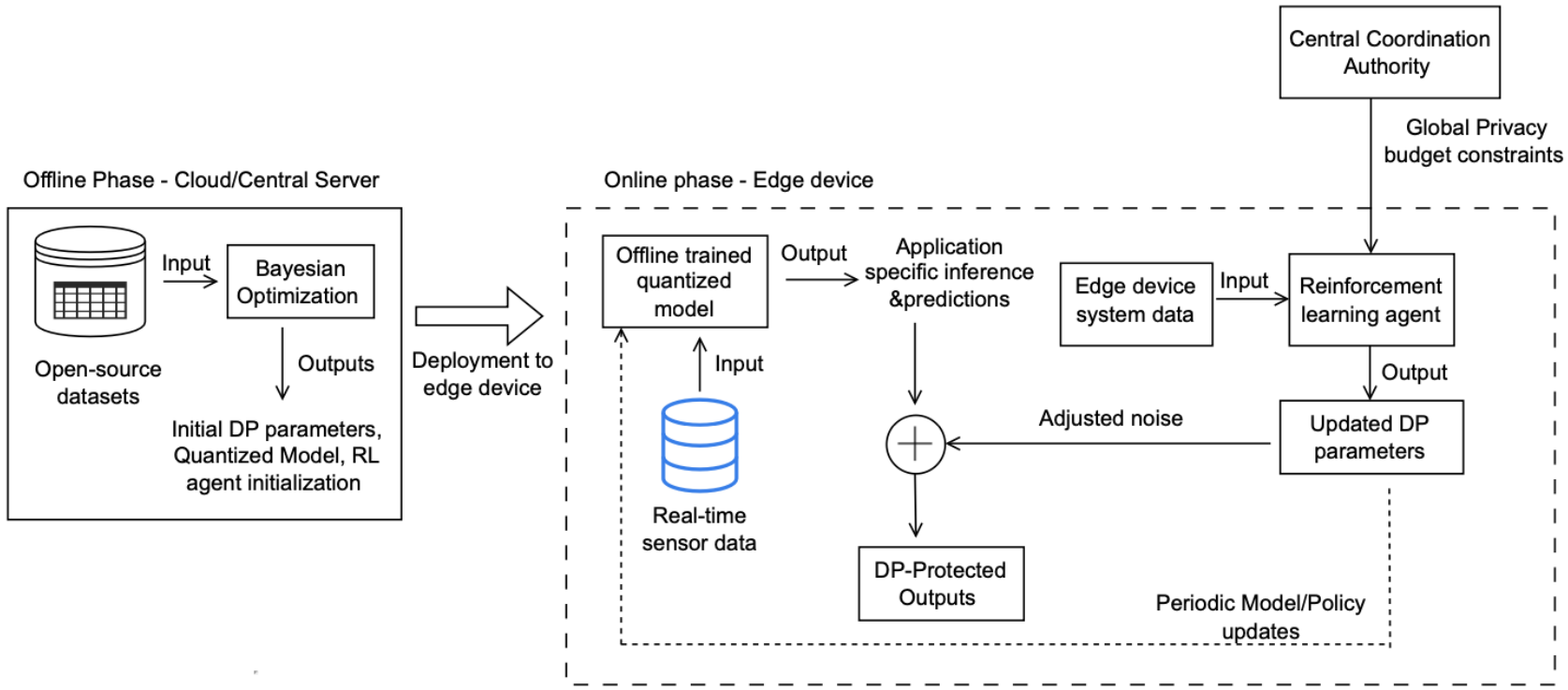



```
linux2@linux2-ThinkPad-T430:~/docker-networking$ sudo docker build -f dockerfile -t lstm-container .
[+] Building 33.0s (7/7) FINISHED
 => [internal] load build definition from dockerfile                                                0.0s
 => => transferring dockerfile: 138B                                                                0.0s
 => [internal] load metadata for docker.io/library/ubuntu:18.04                                     1.3s
 => [internal] load .dockerignore                                                                   0.0s
 => => transferring context: 2B                                                                     0.0s
 => [1/3] FROM docker.io/library/ubuntu:18.04@sha256:152dc042452c496007f07ca9127571cb9c29697f42acbfad72  13.6s
 => => resolve docker.io/library/ubuntu:18.04@sha256:152dc042452c496007f07ca9127571cb9c29697f42acbfad723  0.0s
 => => sha256:f9a80a55f492e823bf5d51f1bd5f87ea3eed1cb31788686aa99a2fb61a27af6a 2.30kB / 2.30kB      0.0s
 => => sha256:7c457f213c7634afb95a0fb2410a74b7b5bc0ba527033362c240c7a11bef4331 25.69MB / 25.69MB    12.2s
 => => sha256:152dc042452c496007f07ca9127571cb9c29697f42acbfad72324b2bb2e43c98 1.33kB / 1.33kB      0.0s
 => => sha256:dca176c9663a7ba4c1f0e710986f5a25e672842963d95b960191e2d9f7185ebe 424B / 424B          0.0s
 => => extracting sha256:7c457f213c7634afb95a0fb2410a74b7b5bc0ba527033362c240c7a11bef4331           1.2s
 => [2/3] RUN apt-get -y update                                                                    16.9s
 => [3/3] RUN echo "varun is at MC"                                                                 0.5s
 => exporting to image                                                                              0.5s
 => => exporting layers                                                                             0.5s
 => => writing image sha256:334123c68d33d33610c87c7c05d3ffdd26f12d37876c96682b2b5b46fdffc089        0.0s
 => => naming to docker.io/library/lstm-container                                                   0.0s
```

```
linux2@linux2-ThinkPad-T430:~/docker-networking$ sudo docker build -f dockerfile-2a -t anova-container .
[+] Building 0.8s (10/10) FINISHED
 => [internal] load build definition from dockerfile-2a                                             0.0s
 => => transferring dockerfile: 871B                                                                0.0s
 => [internal] load metadata for docker.io/library/python:3                                         0.5s
 => [internal] load .dockerignore                                                                   0.0s
 => => transferring context: 2B                                                                     0.0s
 => [1/5] FROM docker.io/library/python:3@sha256:4ea77121eab13d9e71f2783d7505f5655b25bb7b2c263e8020aae3b  0.0s
 => [internal] load build context                                                                   0.0s
 => => transferring context: 878B                                                                   0.0s
 => CACHED [2/5] RUN pip install --upgrade pip                                                      0.0s
 => CACHED [3/5] WORKDIR /ToDoApp                                                                   0.0s
 => CACHED [4/5] RUN python -m pip install --upgrade pip setuptools wheel                           0.0s
 => CACHED [5/5] COPY . .                                                                           0.0s
 => exporting to image                                                                              0.1s
 => => exporting layers                                                                             0.0s
 => => writing image sha256:4af86fec4a4a98989cf3f4d58878d449dbe1dd99150d183d31cf4b441d23edec        0.0s
 => => naming to docker.io/library/anova-container                                                  0.0s
```

Source: End-to-end Docker container testbed IEEE NAECON 2025

Remote care: Security concerns

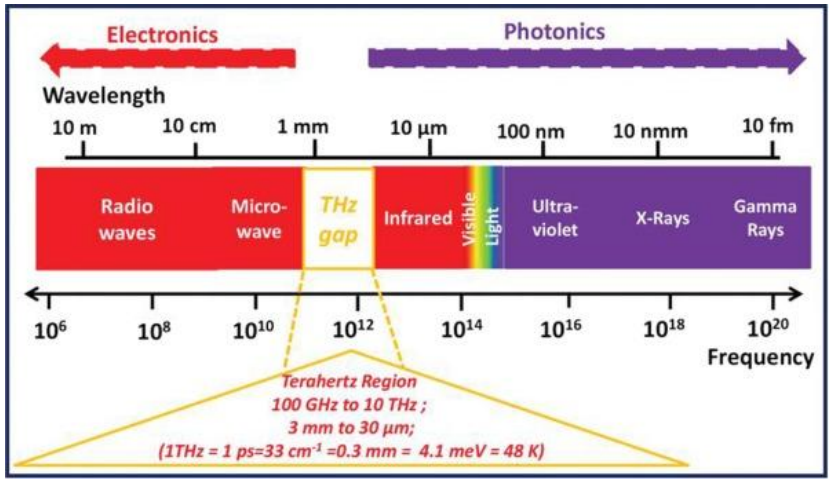


Privacy specific parameters		System and resource constraints	
Notations	**Description**	**Resource constraint**	**Bound**
ϵ	Privacy loss bound	Memory	$\leq$ 512MB
δ	Probability of catastrophic privacy failure	Power	$\leq$ 5W
σ	Noise scale	Inference Time	$\leq$ 100ms
C	Clipping norm	Model Size	$\leq$ 10MB
g_l	Per-layer gradient perturbation	CPU Usage	$\leq$ 75%
ϵ_{total}	Aggregate privacy cost over time	Device Temp	$\leq$ 60℃

Source: Google IRP

AI-Enhanced 6G and Terahertz Communication

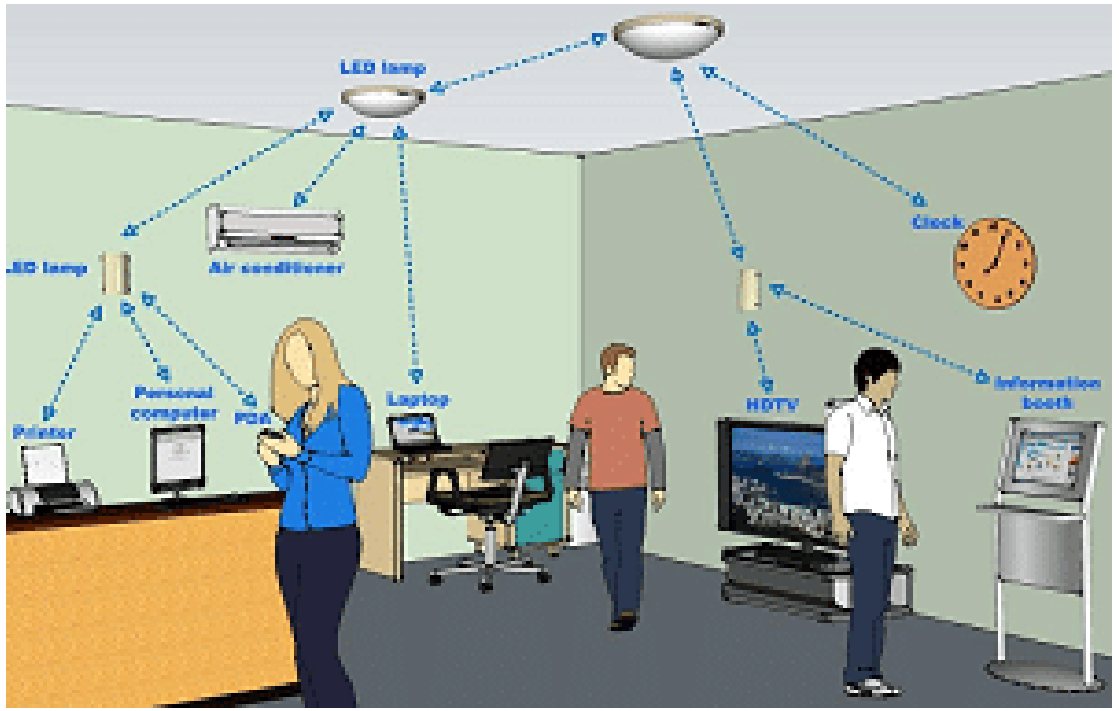
- Terahertz (THz) imaging for early cancer detection
- Benefits:
  - High-speed, low-latency THz links for brain-machine interfaces
  - Non-invasive in nature
  - Remote robotic surgery: 6G enables <1ms latency for haptic-feedback surgical robotics
- Research opportunities:
  - Minimizing tissue absorption and heating effects
  - AI-driven channel modeling for predicting interference patterns
  - Energy efficiency for implants and neural data streaming



Source: Google IRP

Optical and visible light communication (VLC)

- Use cases:
  - Electromagnetic-safe environments
  - Secure hospital networks
  - Smart wards
- Research opportunities:
  - Channel modeling through tissue and fluid
  - Integration with IoMT networks
  - AI based adaptive beam steering



Source: Google IRP

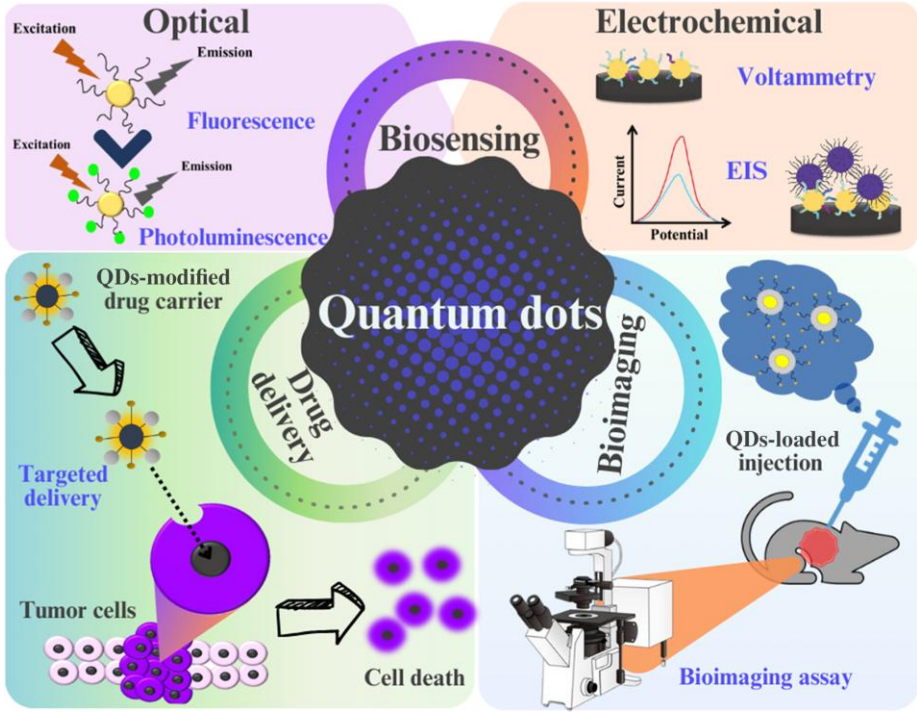
UAVs and Wireless Mobile Health (m-Health) Systems

- Use-cases:
  - Medical drone delivery
  - Post-disaster telehealth
  - Aerial surveillance
- Research opportunities:
  - Reliable UAV-ground communication
  - Autonomous routing and link recovery
  - Secure Communication protocols

Source: Google IRP

Quantum and Nano-communication in Biomedicine

- Emerging area
- Use-cases:
  - In-body nano-networks: Drug delivery nanoparticles
  - Quantum-secure medical data exchange
  - Biphotonic sensing
- Research opportunities:
  - Modeling molecular noise and signal reliability
  - Design of nanoscale transceivers and gateways
  - Quantum key distribution



Source: Google IRP

Conclusion

- Biomedical applications keep evolving
- Extracts the potential of latest/advanced technologies
- Guard rails are important
- Connectivity, reliability, and security are 3 Y's important in advanced applications!

While these technologies expand biomedical connectivity, their reliability and safety depend on autonomous spectrum awareness and adaptive wireless intelligence — exactly what my research enables through real-time autonomous wireless technology detection!

Source: Google IRP

Thank you!

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