Towards Optimized Connectivity in Health Internet of Things Device-to-Device Networks

IARIA

by
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PRESENTER'S BIO

- Dr. Oladayo Bello received her Ph.D. degree in Electrical Engineering from the University of Cape Town. She holds a B.Sc. (Electronics and Electrical Engineering), B.Sc. (Hons) (Industrial and Systems Engineering) and M.Sc. (Electrical Engineering). She also earned a M.S. in Applied and Computational Mathematics from Johns Hopkins University. Prior to joining New Mexico State University, Dr. Bello worked at Monash University and as a researcher with the Council for Scientific and Industrial Research (CSIR). She has also worked in the ICT and Mobile Communications industries and was a Visiting Researcher at the University of California, San Diego. Dr. Bello has authored several peer-reviewed International Journals, Conference papers and Newsletter articles and serves as a reviewer for Journals and Conferences. Her current research interests include Device-to-Device communication in the Internet of Things, Resource Allocation and Optimization in Wireless Networks, Mathematical Modelling of Communication Networks and Curriculum Development for STEM related courses.

OUTLINE

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INTRODUCTION

FOUNDATIONS OF HEALTH INTERNET OF THINGS (HIOT) DEVICE-TO-DEVICE (D2D) NETWORKS

Health Devices	Health Services
• Blood pressure monitors • In-Home sensors • Fitness trackers • Glucose meters • Smart watches • Heart rate monitors	• Patient monitoring • Assisted living • Home care • Remote surgery • Auto-diagnosis • Remote Patients

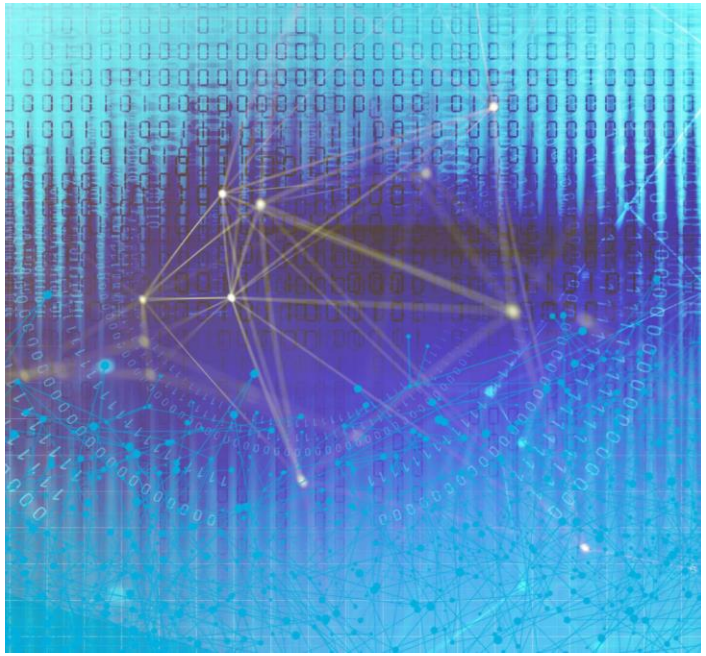
- **HIoT**
  - Connects medical devices, sensors, wearables, clinical instruments and infrastructure
  - **Devices** collaborate **without human intervention** to provide **health services** (real time, proactive)
- **D2D**
  - Intrinsically, **HIoT** will leverage D2D networks
  - **Enables direct connectivity between devices, reduce dependency on central infrastructure**.
- **Objective of the network**
  - **Ensure and achieve optimal network performance in terms of QoS so that reliable health services are provided**
  - **This implies** Low latency, minimal loss, and high throughput
  - QoS is determined by connectivity
- **Challenge**
  - Constrained, wireless, and resource-limited environments and devices and co-existence of traffic with diverse demand influences optimal connectivity

RESEARCH PROBLEM: OPTIMAL CONNECTIVITY

Problem statement

- How to achieve **optimal connectivity for ALL traffic** (in terms of QoS), bearing in mind **constraints** introduced by the devices, traffic and wireless network.
- What is Connectivity?
  - In HIoT, D2D networks implies all QoS demands by active traffic flows are simultaneously satisfied.
- Formal definition:
  - Connectivity $\Leftrightarrow \forall i, f_i(x) \leq b_i$
  - $f_i(x)$: QoS metric performance under configuration x
  - b_i: bound/threshold value for each metric

RESEARCH CONTRIBUTIONS



- **An analysis of the inherent challenges** for optimal connectivity and the limitations of single-objective optimization models in HIoT D2D networks
- **Formulation of optimal connectivity** with a stochastic MO-MF-MC model under the Constraint Based (CB) and Pareto Optimal Vector (POV) perspectives.
- **Justification of POV** as the perspective that best captures the realistic trade-offs among QoS metrics subject to device and environment constraints.
- **Characterization of the uniqueness of traffic flow** in HIoT D2D, as "Mixed-criticality, Bound-assured, Mission-synchronous" (MC-BAMS).

CHALLENGES FOR CONNECTIVITY

INHERENT NETWORK CONSTRAINTS

- **Environmental Constraints**

NFW environments cause stochastic connectivity due to interference, patient mobility, and signal degradation.

- **Device Constraints**

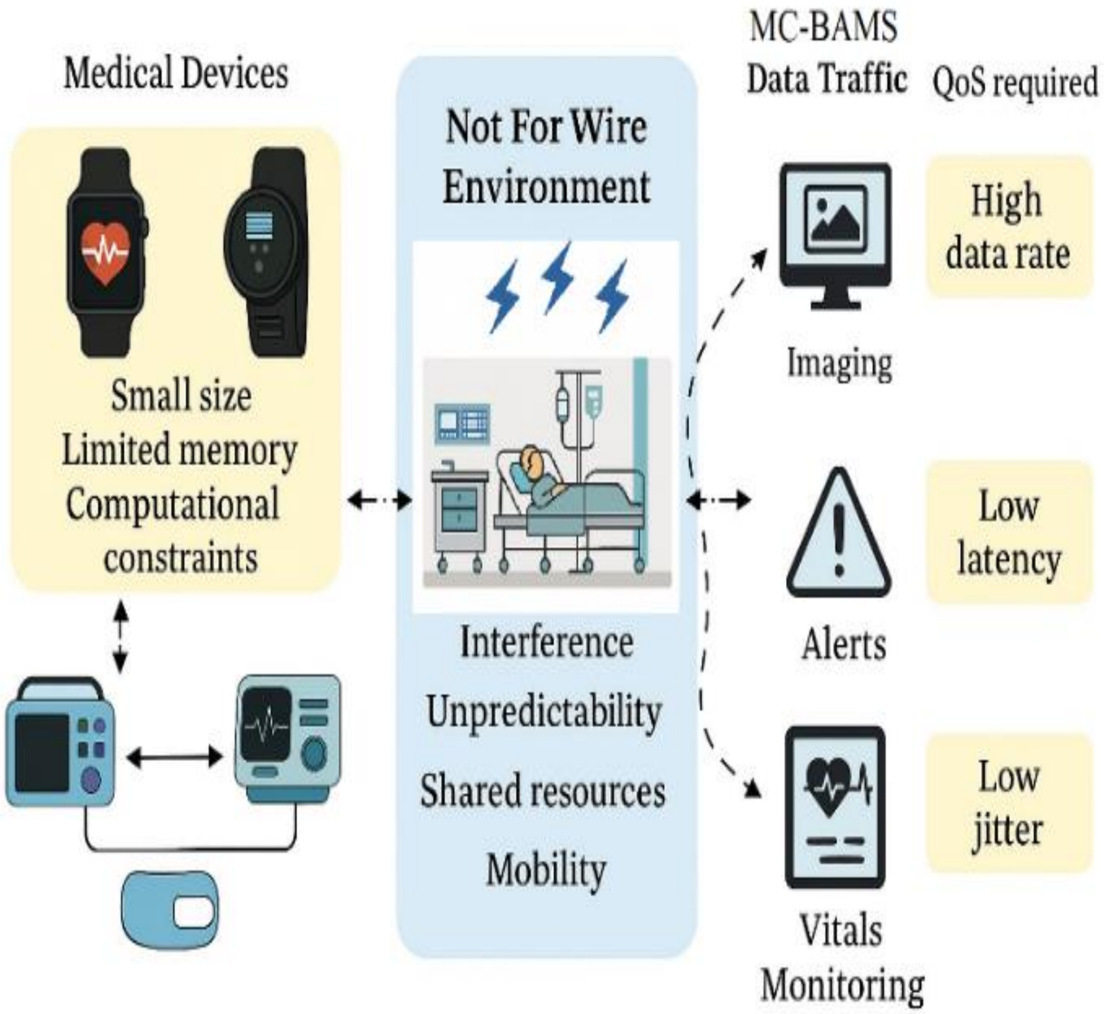
Medical devices have limited battery, memory, and processing power, requiring efficient communication protocols.

- **Heterogeneous Traffic Requirements**

Diverse traffic types need tailored QoS, prioritizing mission-critical alerts over routine updates.

- **Need for Lightweight Protocols**

Current protocols are inefficient; lightweight, adaptive protocols are essential for reliable real-time connectivity.



STOCHASTIC NATURE OF CONNECTIVITY

- **Stochastic Connectivity Characteristics**

Connectivity in HIoT D2D networks varies due to environment and device constraints, requiring probabilistic QoS models.

- **Probabilistic QoS Guarantees**

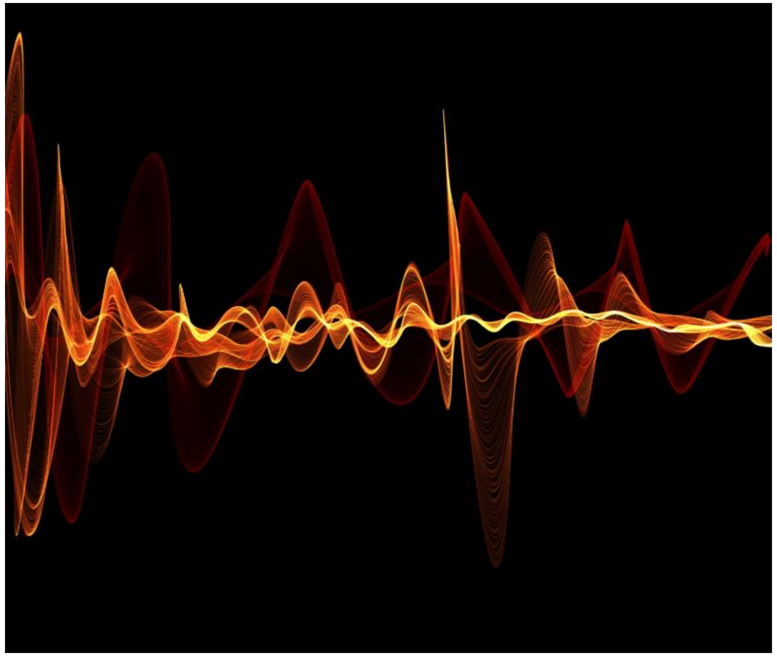
Deterministic QoS is impractical; probabilistic guarantees ensure latency thresholds with specified probabilities.

- **Dynamic Optimization Frameworks**

Optimization must adapt dynamically to changing conditions while tolerating uncertainty in connectivity.

- **Mixed Criticality-Bound Assured Mission Synchronous (MC-BAMS) Traffic Complexity**

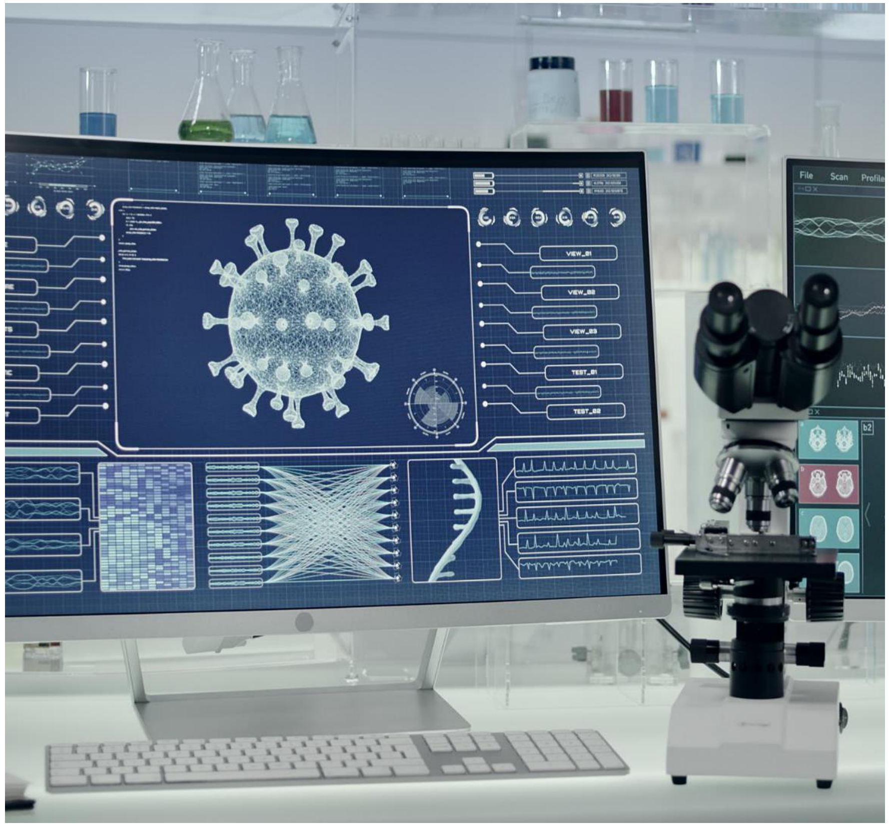
Mixed criticality traffic flows compete for limited resources in unpredictable environments, requiring robust protocols.



OPTIMIZATION STRATEGIES AND GAPS

GAP IN EXISTING MODELS

- Common standardized protocols are not fit for use in HIoT D2D
- Lightweight, adaptive protocols that will overcome the challenges stated are desirable.
  - optimize and allocate resources fairly while meeting stringent QoS requirements of heterogeneous medical data traffic.
  - based on optimization models that will ensure that life-critical communications under device, environmental and traffic constraints.



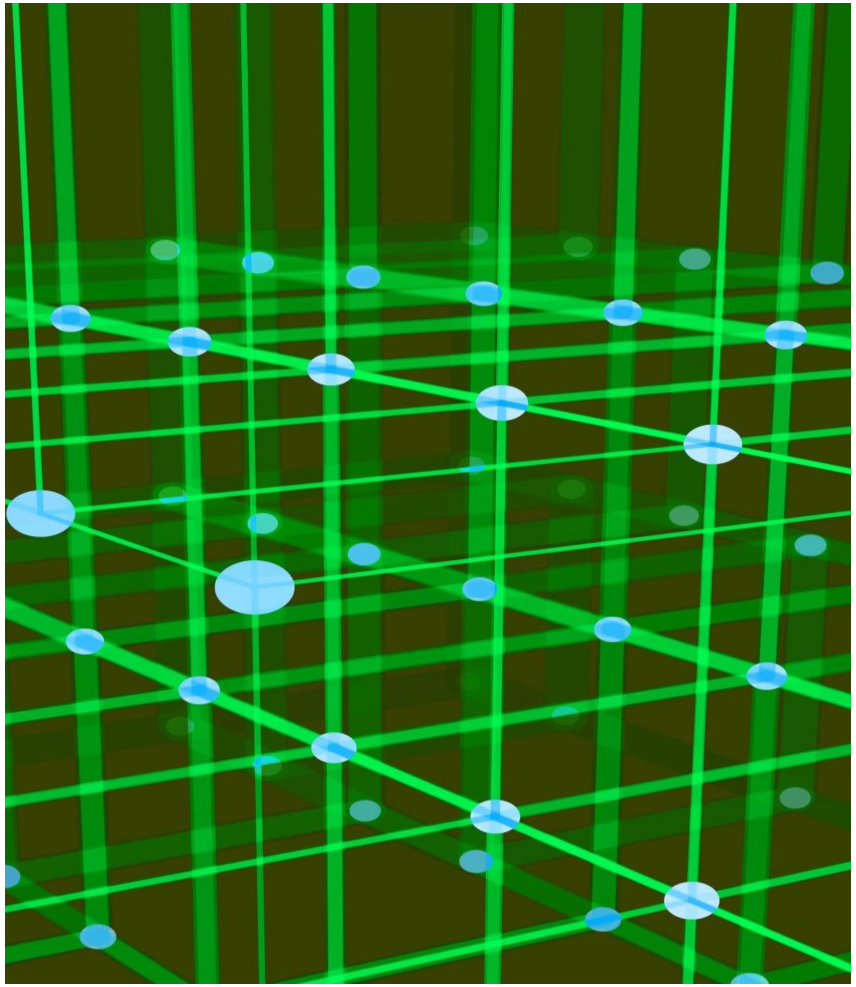
OPTIMIZATION APPROACHES

- **Single-Objective Optimization**
Focuses on optimizing one QoS metric at a time, offering simplicity but ignoring metric interdependencies.

- **Multi-Objective Optimization**
Balances multiple QoS metrics simultaneously, addressing trade-offs for more flexible protocol designs.

- **Advanced Adaptive Methods**
Includes Multi-Objective Reinforcement Learning to learn trade-off policies in uncertain, dynamic environments.

- **Challenges and Future Needs**
Current models face scalability, dynamic constraints, and practical protocol limitations requiring new frameworks.

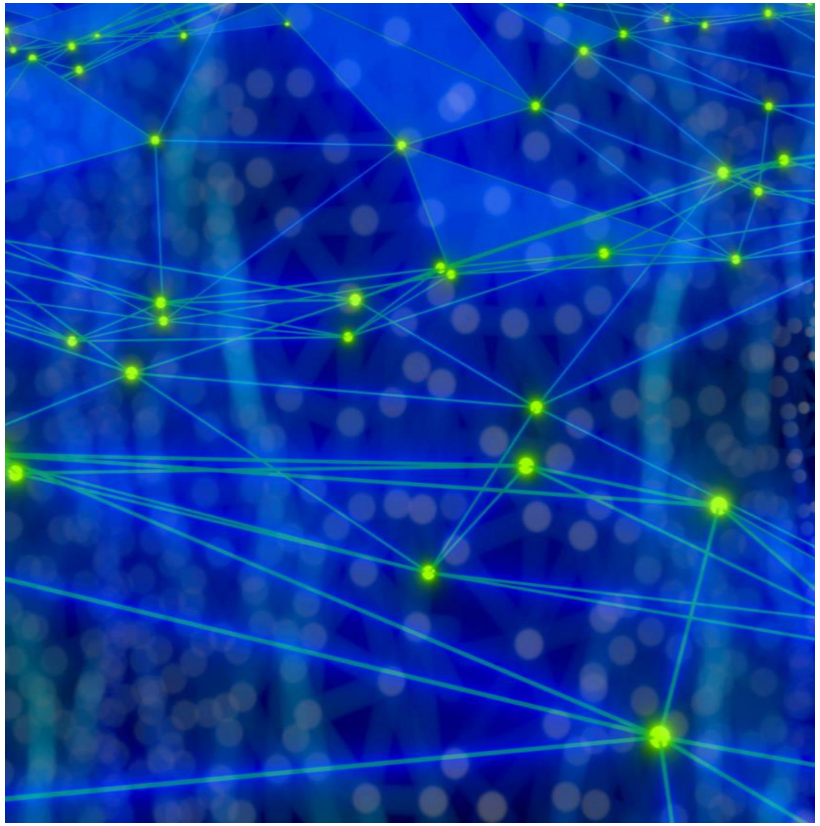


MODELING OPTIMAL CONNECTIVITY

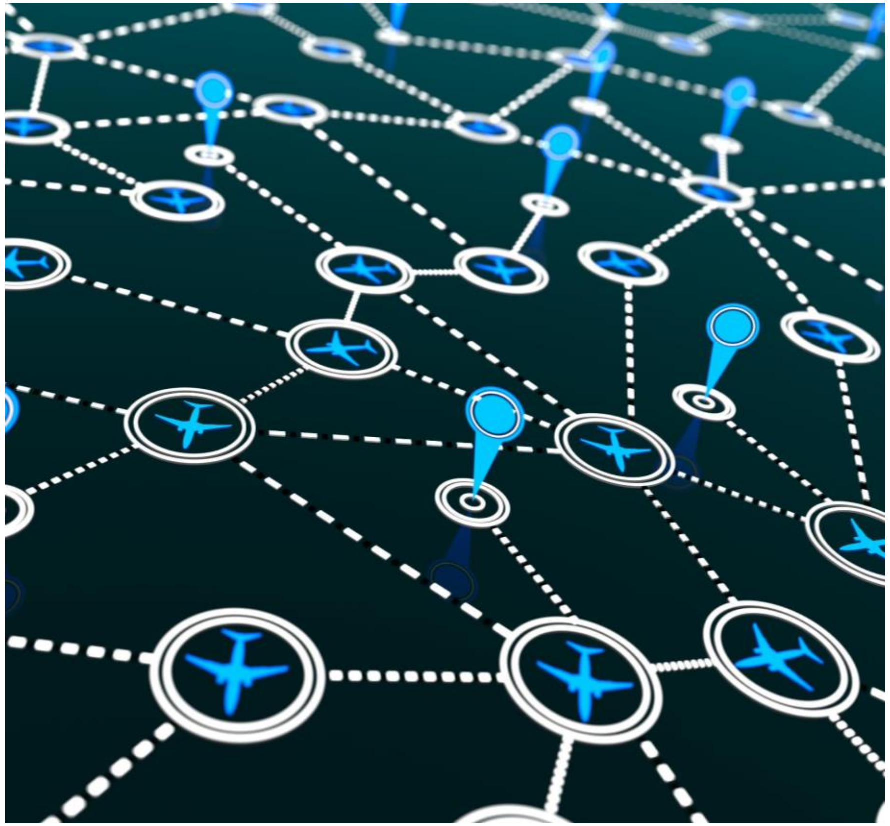
CONSTRAINT-BASED (CB) PERSPECTIVE

Treats connectivity as a feasibility question

- **On a strict binary bound (CB Binary (CBB))**
  - Connectivity is either feasible or not- exists if the specified QoS targets are satisfied; otherwise, it does not.
  - Can be:
    - ✓ Deterministic (CBB-D) -QoS is set with "ideal" conditions of an environment with no uncertainty
    - ✓ Stochastic (CBB-S)- QoS is set with "realistic" conditions, where randomness exists within the network
- **On a stochastic bound (CB Stochastic (CBS))**
  - Connectivity exists when the QoS metric bounds are met with a specified probability.



PARETO OPTIMAL VECTOR (POV) PERSPECTIVE



- **Trade-offs in QoS Metrics**

POV recognizes that improving one QoS metric may require compromising another, enabling more realistic network modeling.

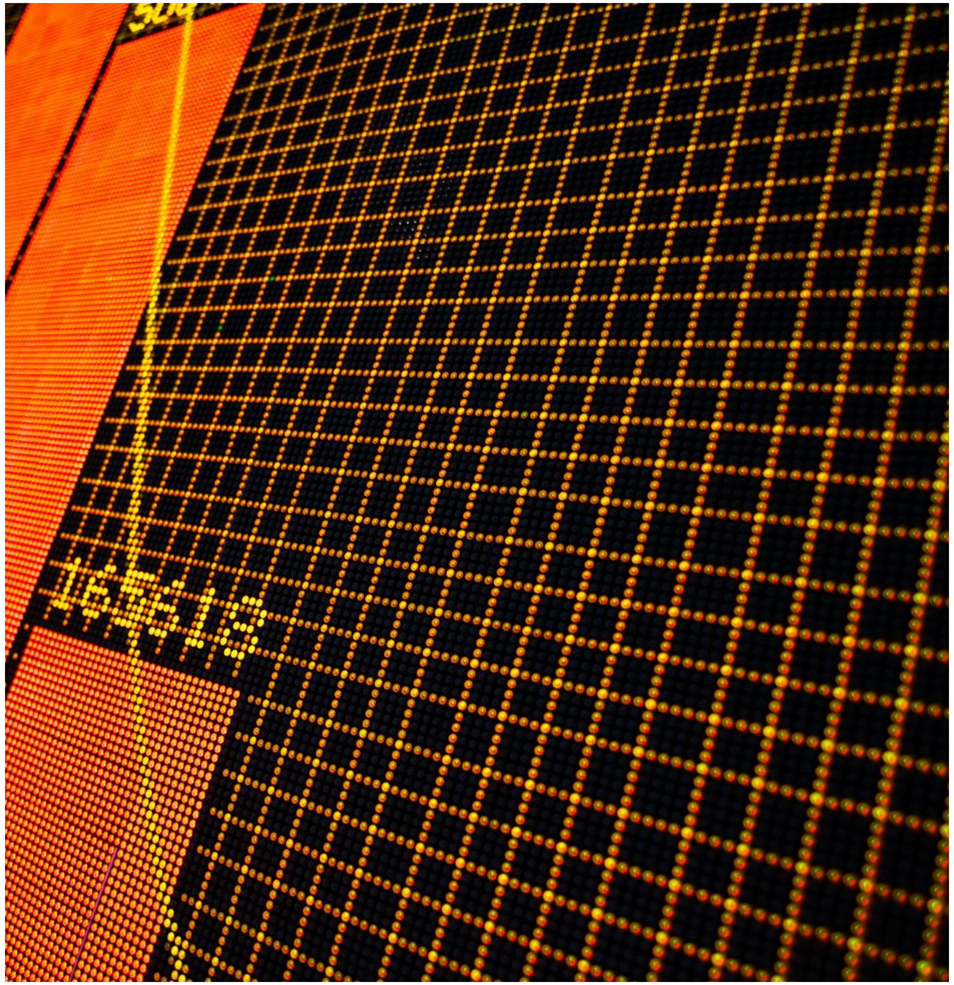
- **Pareto Efficient Vectors and Front**

PEVs form the Pareto front, representing optimal trade-off solutions where no metric can improve without worsening another.

- **Adaptation for HIoT D2D Networks**

POV suits stochastic environments and resource constraints, allowing flexible, adaptive protocol design for HIoT D2D networks.

JUSTIFICATION FOR POV PERSPECTIVE



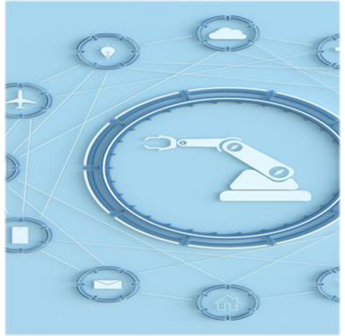
- **Managing Trade-offs in QoS Metrics**
enables managing realistic trade-offs among competing QoS metrics in constrained environments.

- **Adaptive Decision-Making**
supports real-time protocol adjustments based on changing network and healthcare conditions.

- **Application in Healthcare Scenarios**
accommodates different trade-offs, like latency vs battery life, crucial in healthcare applications.

- **Scalable and Practical Model**
offers a scalable, practical foundation for adaptive protocols in constrained medical devices.

CONCLUSION AND FUTURE WORK



Optimized Connectivity Framework

The research models optimal connectivity in HIoT D2D networks under resource constraints using advanced stochastic optimization techniques.

Modeling Perspectives

CB and POV. POV explore trade-offs in QoS metrics for dynamic healthcare environments.

Future Research Directions

Future work targets the development of lightweight networking protocol using POV perspective with real-time learning, and the consideration of energy-awareness, security and safety.

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