

Research Blog

In the Connected Systems and Wireless Networking research group, communication is not treated as just the transfer of data, but as a way of making technology truly useful in the real world. Whether it is a remote sensor in a village, a satellite collecting environmental data, or a smart device operating on limited battery power, the goal is simple: ensure that information reaches where it is needed reliably, efficiently, and on time.

At the heart of this work lies the world of IoT (Internet of Things) and wireless communication. Today, billions of small devices like sensors, trackers, and meters are constantly sending tiny packets of data. These devices often operate in challenging environments: remote locations, harsh weather, or places where network infrastructure is minimal or completely absent. In such scenarios, technologies like LoRaWAN and LPWAN enable long-range communication using very little power, making them ideal for large-scale deployments. But with these advantages come important challenges like how to ensure reliability, how to reduce energy consumption, and how to keep delays low.

One of the key ideas explored in my research group is message replication. Imagine sending an important message multiple times so that even if one copy is lost, another still gets through. This improves reliability, but it also consumes more energy and can increase network congestion. The research introduces smarter ways to handle this trade-off. Instead of simply repeating messages blindly, a hybrid approach is developed where replicas can either be sent separately or cleverly embedded within other transmissions. This balance helps achieve both reliability and energy efficiency, which is something traditional methods struggle to do.

As communication moves beyond Earth's surface, the challenges become even more complex. In direct-to-satellite IoT systems, devices communicate directly with satellites without relying on ground infrastructure. This is especially useful for applications like environmental monitoring, disaster management, and maritime tracking. However, when thousands of devices try to communicate with a satellite, coordination becomes difficult. In such cases, conventional methods like acknowledgments (where the receiver confirms receipt) are not practical.

To address this, the research explores advanced techniques in LR-FHSS (Long-Range Frequency-Hopping Spread Spectrum), where signals hop across frequencies to reduce interference and improve scalability. Here again, intelligent message replication plays a crucial role. Different strategies are studied, sending multiple copies separately or packing them into a single transmission and guidelines are developed to decide which method works best under different network conditions.

Another important direction focuses on efficient data transfer using fountain coding, a technique where data is broken into many small encoded packets. The receiver only needs a sufficient number of these packets (not necessarily all) to reconstruct the original data. While this method is robust, it can waste energy if too many unnecessary packets are sent. To solve this, a feedback-aware mechanism is introduced that helps the sender make smarter transmission decisions. The result is a system that significantly reduces energy consumption by as much as 85% while keeping delays minimal.

Real-world networks are rarely uniform. Some messages are more important than others. For example, an emergency alert must be delivered with high reliability, while routine sensor data may tolerate occasional loss. This research examines how to manage such mixed-priority traffic in simple, low-cost networks that lack advanced coordination features. By comparing strategies like blind repetition and feedback-based retransmission, the work provides insights into how reliability can be improved without negatively impacting other users in the network.

A particularly challenging problem arises when guaranteed delivery is required in situations where losing even a single message is unacceptable. In satellite-based IoT systems, achieving near-perfect reliability is difficult due to unpredictable channel conditions. To tackle this, the research explores the use of incremental redundancy, where additional information is sent only when needed, rather than all at once. This approach allows systems to adapt dynamically, improving reliability while carefully managing energy and delay.

Across all these efforts, a common theme emerges balancing three critical factors energy, reliability, and latency. Improving one often comes at the cost of the others. The work in this area focuses on finding intelligent trade-offs, designing systems that are not just theoretically efficient but also practical and scalable for real-world deployment.

What ties all these ideas together is a broader vision of connectivity without boundaries. From ground-based sensor networks to satellite-linked devices, the aim is to build communication systems that work seamlessly across environments. This includes integrating embedded systems, wireless protocols, and network intelligence to create solutions that are robust, adaptive, and sustainable.

Research in this field does not progress in isolation. It evolves through the interplay of theory, simulation, and real-world constraints. Small improvements in how a message is transmitted or encoded can lead to significant gains in battery life, coverage, or system capacity. Over time, these incremental advances contribute to larger technological shifts enabling smarter cities, more efficient agriculture, better disaster response systems, and improved global connectivity.

As this work continues, the guiding philosophy remains clear: communication systems should not just connect devices but empower applications that improve everyday life. By carefully designing how data moves through networks, especially under constraints the research aims to make connectivity more reliable, energy-efficient, and accessible, even in the most challenging environments.