

# Challenged Networks: The Mobile Internet is Not Connected

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The Internet protocols were designed to provide end-to-end connectivity across heterogeneous networks, yet primarily assuming a “fixed” and rather static network environment. Mobile wireless communication has fundamentally invalidated many aspects of these assumptions, for (heterogeneous) wireless access networks and even more so for mobile ad-hoc networks formed between mobile users. This results in challenged networking environments, facing unpredictable and frequently changing connectivity (capacity, error conditions, delays) and node constraints (energy, computing and storage resources), among others. With the increase in mobile communication devices surpassing fixed ones, future Internet protocols have to address challenged networks adequately.

Experience has shown that imitating stable and reliable connectivity in the wireless domain is often complex and expensive and easily falls short in such environments: ubiquitous mobile communication is not achievable for technical, cost, and social reasons. Yet, in today’s Internet, challenged networks are treated as special cases, often with point solutions of limited applicability.

- Many systems approaches seek to identify a single challenged link and devise approaches to deal specifically with this link (which is quite often, the challenged link is assumed to be connected directly to one of the endpoints running the networked applications).
- Special purpose system and protocol designs for challenged environments, e.g., for sensor networks or mobile information sharing systems, take a vertical approach integrating link layer sensing and medium access control, routing, reliability, and/or application protocol design.
- The research discipline of *Delay-tolerant Networking (DTN)* generally addresses challenged networking environments in which, e.g., very long communication delays or non-existing end-to-end paths may prevent synchronous end-to-end interactions altogether.

The above challenges impact the applications: In the easy case, they will not always work, often reverting back to the user for recovery. In the worst case, challenged networks can prevent them from working at all. Successfully dealing with such conditions will not just help with those “special cases” but also improve robustness in general.

In support of challenged networks in the future Internet:

- Future Internet research should address networking architectures which integrate challenged networks in a natural way and allows performance to degrade gracefully as the challenges increase. In particular, the minimal assumptions about path performance characteristics and the existence of an end-to-end path should be revised. This also requires a wider operational range for infrastructure protocols in support of routing, naming and address resolution, and mobility.
- Application protocol design should be fundamentally revisited to remove artificial assumptions about connectivity characteristics to enable their operation also in challenged environments. Similar considerations will be needed for application layer security. For applications operated by human users, the reconsideration has to go all the way to the user interface design.
- The application protocol considerations will also touch the assumptions the applications make about the communication paradigms and the lower layer abstractions they use. Robustness properties, awareness of the networking environment, the size of meaningful transport units, and possibly the notion of end-to-end are worthwhile revisiting for a future communication substrate. Related to this are operating system aspects and refining the interface between applications and underlying protocols (APIs beyond sockets), which may also provide better awareness of the present networking conditions.

A future research agenda should foster experimentation at all scales, carried out in incremental steps to validate the concepts.