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# Moving towards autonomic, gateway-free cross networking

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*An approach based on Internet Protocol version 6 will provide seamless integration of networks for next-generation devices.*

The new fourth generation (4G) cellular standards that will bring higher Internet bandwidths to mobile devices are built to interoperate with other systems, such as wireless local area (Wi-Fi) networks.[1] The forthcoming 'Internet of things' (IoT) will see billions of smart objects from traffic lights to energy meters sharing information on the Internet.[2] In the face of these developments, it will be crucial to devise a general framework for communication between disparate systems. Internet Protocol version 6 (IPv6)—the next generation of the underlying technology that enables devices to connect to the Internet, currently in the process of being rolled out—is a prime candidate for a common 'language' that can be used to this end.[3]

Because today's networks often use very different communication protocols—and so 'speak' different languages—they must interact with each other through border gateways that act as 'translators'. Figure 1 shows an example of such an arrangement. These types of mediated interactions between separate networks are generically referred to as 'cross networking', and have been the subject of much recent work. For example, our group has studied vertical handover (VHO),[4] which allows nodes to intelligently choose which network to use to access the Internet or other communication infrastructures. Thus, a mobile phone or laptop could switch between cellular and Wi-Fi networks depending on which is in range or which offers better service-quality metrics, such as bandwidth and delay. VHO is typically initiated by the node itself needing to switch connectivity (perhaps because it has moved out of range of one network), so we refer to this as 'single-node' cross networking.

We are also currently investigating mobile data offloading, that is, the strategy of 'deflecting' cellular network data streams into complementary wireless networks (typically Wi-Fi) to prevent saturation in situations such as emergencies or at stadium events, where people all try to communicate simultaneously. Today, cellular operators can add extra base stations to support increased traffic, but with the advent of 4G systems that

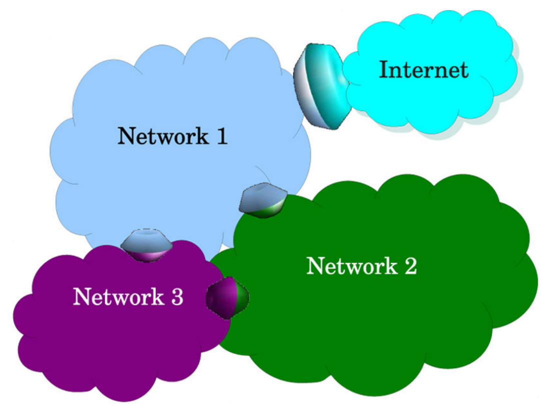


*Figure 1. Cross networking currently relies on border gateways.*

demand ever higher bandwidths, cellular networks alone will not be able to keep up. Early trials of data offloading have been done
using third generation (3G) cellular systems,[5] and data offloading is expected to have a crucial role in 4G systems. The 3rd generation partnership project (3GPP), a telecommunications standards body, has already set forth a reference approach—the so-called access network discovery and selection function (ANDSF)—for enabling (3GPP-compliant) cellular equipment to find and use Wi-Fi networks.[6] Since data offloading can be triggered by an operator or by a multitude of individual nodes experiencing reduced bandwidth, we refer to it as 'network-wide' cross networking. As with VHO, mobile data offloading involves a 'hard' switch between two complementary networks.

Another way cross networking can be used is to efficiently distribute information around a given location. In our work for the Cross-Network Effective Traffic Alerts Dissemination (X-NETAD) project, a primary mobile node (e.g., a smartphone in a car, subscribed to a traffic information service) receives alerts about nearby accidents or road congestion from a cellular network. It then disseminates this information, through multihop Wi-Fi probabilistic broadcasting, to surrounding vehicles belonging to an ephemeral ad-hoc network created around the primary node.[7] In this case, the cross networking is done by

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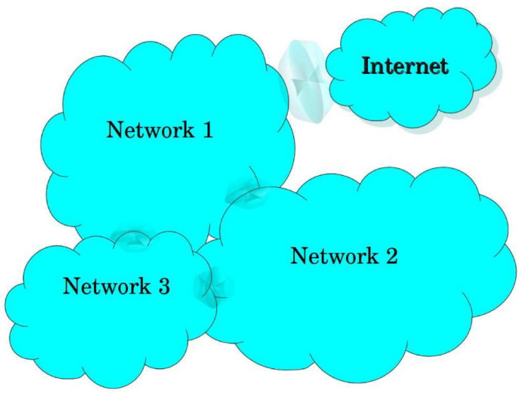


***Figure 2.*** *With autonomic cross networking, the border gateways fade away.*

an intermediate (dual-interface) node that receives information from a primary (cellular) network and shares it through a secondary (Wi-Fi) network.

Finally, in the IoT arena, wireless sensor networks (WSNs) will enable applications such as smart infrastructure monitoring, or smart parking systems that detect free spaces in real time. Since WSNs typically rely on proprietary communication/networking protocols, border gateways are needed to achieve cross networking and connect to the Internet.

We believe cross-network interactions, such as those we have described, could be greatly simplified by implementing 'autonomic' functionality. The idea is inspired by the human autonomic nervous system, which regulates basic bodily functions that are not under conscious control. As proposed by IBM in 2001, the autonomic principle could be applied to the design of large and complex communication systems, such as future wireless networks (4G and beyond), in which self-discovery, awareness and analytical capabilities would play a major part. Such self-organizing functionality is indeed already envisaged in the 4G 3GPP approach for long-term evolution systems that deliver high-speed mobile data.

Whereas the present-day instances of cross networking outlined previously call for a 'hard' switch (triggered by a single or multiple nodes in response to pre-established conditions), the autonomic approach would extend this by implementing self-aware mechanisms in the node protocol stacks to enable 'self-organizing' cross networking, which does away with border gateways. With this aim in mind, IPv6 is of interest because it is built from the ground up to support interoperability and mobility, with a vast address space that enables a virtually unlimited number of devices to connect directly, and a flexible, scalable architecture. Because of these inherent benefits, current research on the IoT is pushing towards ubiquitous IPv6-based communications, even for resource-constrained smart objects. This will open up unprecedented scope for cross networking, as heterogeneous networks increasingly share IPv6 as a common language (4G systems are IP-based.) To further this aim, the European Union project CALIPSO (Connect ALl IP-based Smart Objects!) is working to achieve IPv6 end-to-end connectivity all the way into smart objects, by means of compact, energy-efficient and loss/failure-tolerant routing and radio protocols.[8] This will pave the way for fusing together different networks (see Figure 2). Once nodes speak the same high-level language (IPv6), implementing autonomic core functionality at a low level will make it possible to perform efficient cross networking, allowing the gateways to fade away (although they might survive for energy-efficiency reasons.)

In summary, we have seen how interactions between heterogeneous networks typically rely on gateways that act as translators. However, current research activity on the IoT and the envisaged role of IPv6-based communications between smart objects point to autonomic IPv6-oriented cross networking as a promising new approach. We plan to explore this in the future by designing a set of basic communication rules, at the hardware and lower operating system levels, that allow a node to autonomically choose the best way to connect to the Internet.

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