# Unifying Micro Sensor Networks with the Internet via Overlay Networking

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Today's architecture for interconnecting WSNs and the Internet is based on treating a WSN as a separate entity from the Internet. Our approach to unifying sensor networks with the Internet is instead to decouple the relationship between the API-enforced database view and the gateway, making the gateway more general by introducing application-level overlay networking into the gateway. In our approach, sensor network packets, rather than being stopped at the gateway, are instead encapsulated into IP packets, and then directed from the gateway to any number of interested applications and services residing remotely on the Internet. The basic encapsulation procedure forms an application overlay of the sensor network *over* the Internet. Instead of being restricted by a database API, all applications will have direct access to a networking API that allows them to query and interact with the sensor network directly via a largely transparent gateway. Applications that still desire a database view of the WSN can still query the WSN through a database API. Thus, this approach of transforming the gateway into primarily an application-level packet relay will continue to be compatible with current approaches such as TinyDB, while encouraging proliferation of new applications and services.

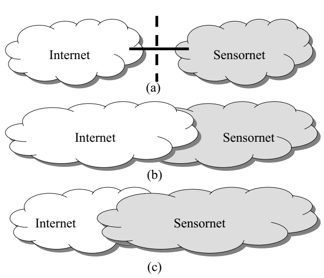


Fig. 1. Architectures for Integrating Sensor Networks with the Internet: (a) Application Gateway or NAT (b) IP overlaying sensor network (c) sensor network overlaying IP

Possible architectures for interconnecting the Internet with heterogeneous sensor networks includes Gateways, Network Address Translation (NAT), IP overlays, and sensor network overlays as is illustrated in  1. The major limitation of both NAT and IP Overlay is that these approaches assume that the sensor network employs addresses. Data-driven content-based routing within sensor networks, e.g. directed diffusion [1], can be address-less. Our architecture reconciles address-less and address-based routing by extending address-less sensor network routing into the Internet as an application overlay.

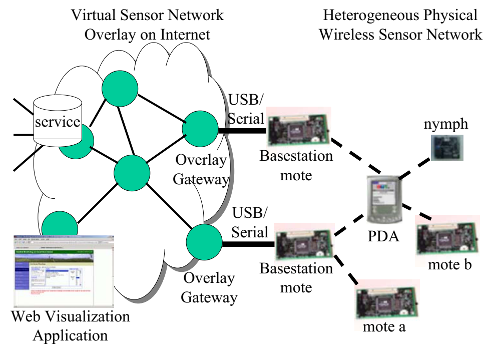


Fig. 2. Virtual nodes (circles) form a virtual sensor network overlaying the Internet and seamlessly interconnect with real sensor nodes via overlay gateways.

As sensor network packets reach the border with the Internet world, these packets will be *encapsulated* within TCP/IP (or UDP/IP) packets and will then be sent as an application layer packet over the Internet to the appropriate application end point on a remote IP host. Effectively, each layer on the sensor network protocol stack (application, transport and network) sits above or *overlays* the Internet protocol stack. The gateway only needs to understand the "lowest" level, e.g. network layer, of the sensor network as well as how to handle the differences between IP and WSN routing.

The essential features of the proposed overlay network structure are illustrated in Figure 2. The major components include the *virtual nodes* running over the Internet and the *overlay gateway*. The sensor overlay permits a rich and versatile environment for the interconnection of virtual nodes, which collectively form a *virtual sensor network*.

A virtual node is defined as any entity that communicates with peer entities on a real sensor network through a common set of protocols, network layer and above. Virtual nodes route packets the same way that physical sensor nodes route packets. Each virtual node therefore functions at least as an application-level router of sensor network packets over the Internet. They also interpret transport layer packets in the same manner that physical sensor nodes interpret them. This is all possible because the entity that interconnects the two worlds, namely the *overlay gateway*, preserves sensor network layer headers and payloads destined for the Internet, encapsulating the entire sensor network packet within a TCP/UDP/IP packet. Figure 3 shows the specific operation of an overlay gateway. Packets

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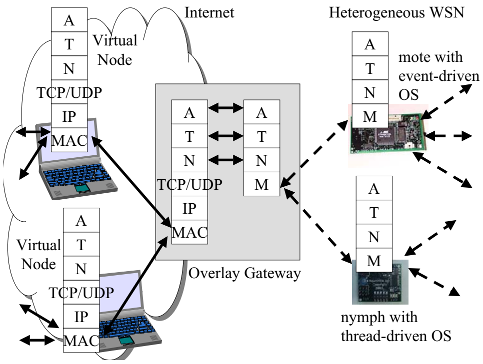


Fig. 3. The sensor networking stack is preserved by the overlay gateway (network layer and above: A, T, and N), creating an application-level overlay over the Internet. A=sensor application layer, T=sensor transport layer, N= sensor network layer, M=sensor MAC layer

that arrive at the overlay gateway from the sensor network will have MAC(M), network(N), transport(T), and application(A) layer headers specific to the sensor network. The overlay gateway will then propagate the packet's network layer and above headers (N,T,A) and application payload to the Internet, encapsulating them within TCP/UDP/IP packets. The overlay gateway effectively translates the sensor network's protocol stack, formerly layer 3 and above, to the application layer and above on the Internet. Virtual nodes therefore form a virtual sensor network that operates as an application-level overlay of the Internet. The overlay gateway itself is also a virtual node that participates in sensor network routing decisions. Unlike application-level gateways that require semantic knowledge of each application in order to make a routing decision, the overlay gateway routes based on sensor network layer information. Our expectation is that the number of sensor network layer protocols will be far smaller than the number of applications and application layer protocols and will not change rapidly. The overlay gateway is tasked with executing this small, relatively well-known and stable set of sensor network layer protocols. Meanwhile, the number of applications can proliferate freely above the network layer, without the overlay gateway posing a bottleneck to innovation.

As defined by the application-level overlay, the user-level network stack, and the common sensor networking API, the virtual sensor network is quite general. Virtual nodes can run on any distributed combination of IP hosts. Thus, applications that are far from the physical deployment can directly interact with an in-situ sensor network remotely. Multiple virtual nodes can run on the same IP host. We believe that this interconnection architecture holds promise for testing and experimentation by enabling simulation environments such as TOSSIM [2] to be connected in a structured way with real world sensor networks. In additon, this model does not constrain the hybrid physical/virtual sensor network to communicate via only one gateway. An arbitrary number of overlay gateways is permitted.

Typically, sensor network applications are initially tested either in simulation or in a small scale test deployment

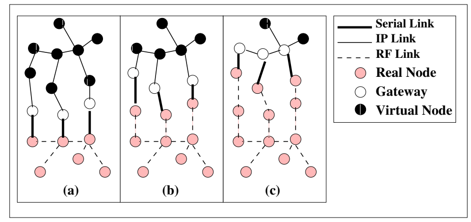


Fig. 4. Phased deployment of sensor nodes

before the actual real deployment. Both these methods fall short of thoroughly testing the sensor network application leading to unforeseen problems. The overlay structure allows phased deployment of the sensor network application into the physical world. Initially, a set of virtual nodes are simulated in the virtual environment. As the sensor network application is developed and tested, more real nodes are deployed into the physical environment, leading to a controlled, phased deployment from the virtual world to the real world, as shown in Figure 4.

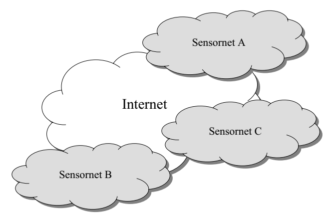


Fig. 5. Multiple sensor network overlays over IP can coexist independently.

Sensor network overlays over the IP network provide a sound foundation for managing geographically distributed WSNs. Application-level overlays have the power to *differentiate* application-specific sensor networks, and also have the power to *integrate* related but geographically distributed WSNs into a single *virtual sensor network*. For example, Figure 5 illustrates the former case, where multiple sensor network overlays can coexist independently on the Internet without conflicting with each other. These networks may even be physically overlapping and their sensor nodes may be interleaved. The overlay gateway can be programmed to make it appear as if each set of sensor nodes in the same WSN is logically distinct in its own application-level overlay. Conversely, application-level overlays permit geographically separate WSNs to be unified into a single virtual WSN, much like a virtual LAN or a virtual private network (VPN). This simplifies remote management of a sprawling WSN consisting of many smaller physically distinct WSNs.

## References

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