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Executive Summary

What innovations will shape supply chains a decade from now? It is impossible to know for sure, but given the frenetic pace of technological development, companies need to be on the lookout for breakthroughs that could radically alter the way supply chains are designed, built, and managed. Key to priming organizations for such transformative change is being aware of germane technologies that are emerging today. Even early-stage concepts that might not seem directly relevant may evolve rapidly and have a profound impact on future operations and hence competitiveness.

As an example, consider a technology that became a game-changing innovation around the globe over a few decades. In the 1960s, Dr. Ivan Getting, a former MIT professor of electrical engineering, was engaged on research into guidance systems for military aircraft and missiles. At the time, the work was considered relevant only for military applications and far too expensive for wider use. However, the project helped pave the way for the launch of the first experimental global positioning system (GPS) satellites a decade or so later, and ultimately to the GPS network that is now in ubiquitous use as a tracking system.

To help companies identify technologies that might transform future supply chains, the MIT Center for Transportation & Logistics (MIT CTL) is publishing a series of white papers on innovations that have the potential to transform future supply chains. In this paper, we take a look at ultra-low-power sensing. Under the leadership of Professor Anantha Chandrakasan, MIT professor of electrical engineering and computer science and director of MIT’s Microsystems Technology Laboratories (MTL), researchers are developing a new generation of sensors and radio transmitters with groundbreaking capabilities.

One of the features that distinguishes the technology is its extremely low power consumption. Powered sensing devices can be deployed
for long periods, extending the number and type of possible applications. Also, sensors can transmit data without the need for costly infrastructure, again opening up new application areas.

The vast potential of ultra-low-power sensing is being demonstrated in the medical field. MTL researchers have designed miniature sensing systems that gather information on a patient’s vital signs and relay the data to remote healthcare providers and experts who can be thousands of miles away. The impact on supply chains has yet to unfold, but there are a number of obvious possibilities. Applying the technology to the flow of goods could revolutionize product tracking, for instance. The low-power sensors would transmit data continuously without the need for scanners, and communicate the data to the web for wider dissemination to authorized users, such as upstream and downstream trading partners.

There are many challenges still to overcome. The wireless devices need to deliver dramatic improvements in accuracy and cost compared to existing tracking technology, such as radio frequency identification (RFID). However, the rate at which this new frontier in sensing applications is moving forward suggests that such deliverables are possible.
Many technologies currently under development – and many that have yet to appear – have the potential to redefine supply chains. But advances in sensing are particularly interesting given the tremendous impact that innovations in this area could have on end-to-end supply chain management. Ultra-low-power sensing is an exciting new development in the field. Although it is still evolving, the technology has already proven its worth in real-world applications.

When MTL received federal funding in 2006 to develop a system small and powerful enough to control the flight of an insect, the devices that the MIT research center is now developing began to take shape. The idea was to create a means of collecting environmental information using the highly sophisticated flight capabilities of these creatures. Various research teams worked on the project over the next few years. MTL focused on the electronics needed to exchange signals between the flying insect and the controller. The device had to be extremely light and small, and consume a minuscule amount of power.

At MTL, the team created a tiny bundle of electronic components that included control circuits, a battery, and a radio receiver that weighed about one gram, and consumed on average less than one milliwatt of power. The unit was attached to a moth, and flight control commands were transmitted to the receiver using ultrawideband transmissions in short bursts. “Basically, you send a very narrow pulse every time you want to transmit something, using low-cost electronics and low power,” explains Chandrakasan.

The project inspired further research, particularly in the field of medical sensing. Today, MTL is developing an electronic package the size of a skin patch that can be worn by at-risk patients. The device, dubbed the electronic Band-Aid, includes sensors, a battery, computer chips, and a radio transmitter/receiver, and transmits important physiological data to distant healthcare providers.
The team also is working on a system that uses a group of sensors embedded in textiles that form a Body Area Network (see Figure 1). The signals can be securely transmitted via a local relay such as a cell phone to the Internet.

There are numerous ways in which the system can be deployed. An individual who has suffered a heart attack could wear the unobtrusive patch rather than being hooked up to unwieldy monitoring equipment. Another possibility is to program the unit to detect and transmit the warning signs of brain seizures and guide responders to sufferers.

A recently developed chip can recognize the telltale electroencephalograph (EEG) patterns that precede a brain seizure. A micro sensor equipped with the chip is attached to the scalp and transmits alerts when an epileptic person is about to have an attack. Sensors capable of analyzing other physiologic signals are emerging.

These innovations are made possible by recent advances in low-power microelectronics. “One of our innovations is building radio devices that consume very little energy and transmit over long distances,
much longer than RFID, for example,” says Chandrakasan. “At the same time, we optimize the devices for the kind of data rates that are compatible with the sensors being used.”

Work is under way to reduce power consumption levels to a point where the need for batteries with a limited life is eliminated. The researchers are developing personal monitoring devices that scavenge energy from the wearer’s body heat, for instance. Other alternative power sources include the use of materials that generate an electric current when under pressure, and harnessing energy from small movements and vibrations. Techniques such as these that extend the working life of monitors are especially important for implantable devices.

Since solar power or ambient light could drive future sensing devices, MIT researchers are developing more efficient solar cells for external and internal applications. “We are looking at how to efficiently convert the output from a solar cell into a usable output for electronics. To do this, you need the energy management circuitry, and this is one of the contributions we are making,” says Chandrakasan.

Supply Chain Prospects

The combination of inexpensive, miniaturized electronics, long operating range, and miserly energy needs could make ultra-low-power radio technology an attractive option for various supply chain applications including tracking. As Chandrakasan points out, the rate at which data on the status of shipments needs to be collected and transmitted is low, so the power requirements are relatively modest. These demands can be reduced even further using some of the techniques that MTL has developed. For instance, the devices can transmit data in bursts and switch to sleep mode between transmissions to conserve power.

Of particular interest is the ability to transmit data on the status of tagged units, such as pallets, to external networks without the need
for handheld or stationary readers. Eliminating this equipment also would reduce infrastructural costs and remove a primary source of data error. Another compelling feature of the technology is that it makes tracking data instantly available to authorized users via the Internet. Existing supply chain tracking systems are hampered by delayed data and information gaps.

These problems were aired at the MIT CTL symposium on Capturing Strategic Advantage from Integrated Data Signals held in October 2010. A number of companies confirmed that the distribution of demand data in retailing environments to upstream trading partners is unreliable and spotty even though the technology has been available for almost two decades. A system that relays such data efficiently and that can transmit alerts to a variety of devices, including managers’ smart phones, offers huge advantages.

“Think of the communications network that does not exist today because of the limits on power and the ability to collect data from sensors. If you take away these constraints [based on MTL’s work], a lot of possibilities open up,” says Jim Rice, Deputy Director, MIT CTL.

Jared Schrieber, Vice President, Products and Services, at retail execution management company Retail Solutions, points to the possibilities created by existing tracking applications. “RFID applications that have performed well represent early adoption opportunities for this new technology, because there is already a proven use case with a return on investment for RFID,” he says.

**Application Areas**

Ultra-low-power sensing is in its infancy, and the use cases for supply chain are theoretical. By exploring potential applications, however, we can envision possible uses for the technology. Tracking cargo in transit is one promising area. An example is sensors mounted on container vessels that use wideband transmissions to periodically broadcast updates on cargo status that are relayed to the Internet. These devices could be powered by solar energy or other sources,
such as the ship’s motion, engine vibrations, or, in the case of reefer containers, temperature differentials between the interior and exterior of the boxes. Perhaps trucks and railcars can be wired in a similar fashion.

There are a number of potential indoor applications. Consider a network in a retail outlet that automatically transmits regular updates on the status of inventory without the need for scans from readers. Tracking product within stores is still a problem for many retailers. “If you had a monitoring capability that is continuously tracking inventory for a given product in a given area of the store, then you could provide better information for associates,” says Schrieber.

Similar applications can be envisaged for distribution centers, perhaps using sensors that are powered by ambient light. Also, working environments where inventory tracking is a challenge might benefit from the technology. “Think about hospitals where critical items can be tagged,” says Chandrakasan.

Beyond tracking, the technology has the potential to take supply chain analytics to higher levels. As can be seen in the medical applications described earlier, reducing the power demands of sensor components frees up analytical capacity. This could be used to gather, process, and communicate more detailed information on products moving through supply chains, improving risk management and providing decision makers with more accurate information on product availability.

Coupling potentially new analytical capabilities with innovative operational designs may enable firms to rapidly adapt supply chains to shifting market conditions and emerging opportunities with unprecedented precision. This level of agility is expected to become increasingly important over the next decade. A worldwide tracking system unencumbered by readers and power constraints that provides unbroken, real-time data could finally enable companies to realize the vision of true end-to-end visibility in supply chains.
Unresolved Issues

Still, there are a number of difficult challenges to overcome. Schrieber believes that the technology has to address the two major drawbacks that have impeded the adoption of RFID: low accuracy and high cost. “If not, you might get 5–10% more use cases than RFID, but it will be an incremental advance and not a breakthrough,” he says.

In retail store environments, RFID readings are only about 65% accurate estimates, notes Schrieber, so there is considerable scope for improvement. Across the supply chain, factors such as pallet configuration, the presence of metals and liquids, the speed of cargo flows, and damage to tags can cause erroneous RFID readouts. “If a technology can achieve 99% accuracy, then this has phenomenal implications for tracking,” Schrieber says.

Ultra-low-power sensing also has to be viable from a cost standpoint. “If these are tags for consumables, the cost needs to be one or two pennies each,” believes Schrieber. Whether the cost can be brought down low enough for item-level tracking has yet to be determined. However, MTL is confident that for mass-market applications where the number of tracking devices is high, the cost could be brought down to a few cents per unit.

Scope for Success

In the 1960s, few people could have predicted that research into missile guidance systems would culminate in the creation of a GPS system. Ultra-low-power sensing may or may not follow a similar development path, but the technology is advancing rapidly and will likely produce further breakthroughs over the next decade.

The combination of negligible power demands, absence of restrictive infrastructure, and the creation of broader information networks has the potential to bring about structural changes in supply chains that spawn new processes and alter the economics of moving goods efficiently.
“We are taking innovations in sensors and communications and reducing the amount of energy required by an order of magnitude,” says Chandrakasan. “There are some amazing advances in what electronics can do, and a lot of the exciting opportunities lie in thinking about applications such as supply chain.”

**Next Steps**

MIT CTL is exploring potential supply chain applications for a number of cutting-edge technologies. For more information, contact: Jim Rice, Deputy Director, MIT CTL, at email: jrice@mit.edu.

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About the MIT Center for Transportation & Logistics: MIT CTL has been a world leader in supply chain management research and education for more than three decades. Combining its cutting-edge research with industry relationships, the Center’s corporate outreach program turns innovative research into market-winning commercial applications. And in education, MIT is consistently ranked first among business programs in logistics and supply chain management.

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