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TACKLING THE TOO-MANY-DEVICES PROBLEM

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YOUNG REVIEWERS:

HARRY

Integrated sensing and communication (ISAC) is a new technology designed to solve the problem of "device clutter". By combining sensing and communication into one system, ISAC reduces the need for extra devices, saves energy, and makes networks faster and smarter. It helps devices respond to changes in their surroundings, like adjusting a smart home's temperature. ISAC is already being tested in exciting ways. ISAC sensors could help farmers save water and fertilizer, and sensors could quickly detect power grid issues such as outages, changes in electricity flow, or equipment failures. ISAC systems can enable connected cars to drive autonomously and detect obstacles, while coordinating with each other to improve traffic flow in big cities. ISAC systems could also help monitor patients in hospitals. While there are challenges, like making systems work smoothly together, ISAC has the potential to make networks simpler, more efficient, and better for the planet.

THE WORLD NEEDS LESS DEVICE CLUTTER

Have you noticed how many devices we have around us to do everyday tasks? In your house alone, you might have a smart speaker for playing music, a tablet for streaming videos, a Wi-Fi router for internet, a thermostat that adjusts the temperature, and a doorbell camera to see who is outside...and more! It seems like the number of gadgets we rely on is growing every day. While these devices can make life easier and more fun, having so many of them results in what is called device clutter—too many devices doing similar tasks. This leads to wasted energy, slower communication between devices, and the need for more resources like the silicon used to build electronics [1]. At the end of their lifetime, these devices end up in landfills; so the more devices we have, the more electronic waste (**e-waste**) we must deal with down the line.

E-WASTE

Old, broken, or unwanted electronic devices like phones, computers, and batteries, which often contain harmful materials.

Traditional networks rely on two types of systems: **sensing systems** and **communication systems**. Sensing systems collect data about the world around us—like air quality monitors that measure pollution levels or soil sensors that check moisture levels on a farm. Communication systems, on the other hand, send and receive information, like Wi-Fi routers that let you play live games, stream videos, or make video calls. These systems often work side by side but are built separately, meaning more devices, more energy use, and more chances for things to go wrong.

SENSING SYSTEMS

Devices that collect data about the world around us, like soil sensors that check moisture levels or air monitors that measure pollution.

COMMUNICATION SYSTEMS

Devices that send and receive information, like Wi-Fi routers that let you stream videos or make video calls.

To solve the problems caused by the growing tangle of networks and devices, we need smarter, multi-functional devices that can do many things, and smarter networks that reduce device clutter, save energy, and make communication more efficient.

EMERGING TECHNOLOGY: INTEGRATED SENSING AND COMMUNICATION

Integrated sensing and communication (ISAC) is a new technology designed to tackle the too-many-devices problem. ISAC combines the two important functions of networks, sensing and communication, into one system [2, 3]. This means that the same system can collect data about the environment *and* share that information with other devices. By combining these tasks, ISAC can help reduce the number of devices we need, save energy and resources, reduce e-waste, and make networks faster and smarter.

INTEGRATED SENSING AND COMMUNICATION (ISAC)

A technology that combines collecting data and sharing information into one system, making networks faster, simpler, and more efficient.

ISAC does not just combine tasks; it also helps networks understand their surroundings, making devices intelligent and aware of what is happening nearby so they can adjust their behavior as needed. For example, a smart home device using ISAC could detect whether people are in a certain room and send that information to a heating or

cooling system, adjusting the temperature automatically. On a larger scale, ISAC can help systems make smarter, more efficient decisions in complex environments, like warehouses. For example, it could allow a smart warehouse to track workers or equipment in real time and send updates to managers or automated systems to keep everything running smoothly. In a smart-city environment, ISAC could enable **connected cars**, self-driving cars that can detect a traffic accident and communicate it to cars in the surrounding area, to avoid congestion. Whether in homes or industrial settings, ISAC's ability to sense changes and communicate about them at the same time is made possible by advanced programs that figure out how to do both tasks efficiently, saving time, and energy.

CONNECTED CARS

Modern cars that use sensors and communication tools to monitor their environment, navigate autonomously, and communicate with each other and to traffic authorities.

TECH TO THE RESCUE

ISAC is already being used in some exciting ways, to solve real-world problems in several industries (Figure 1).

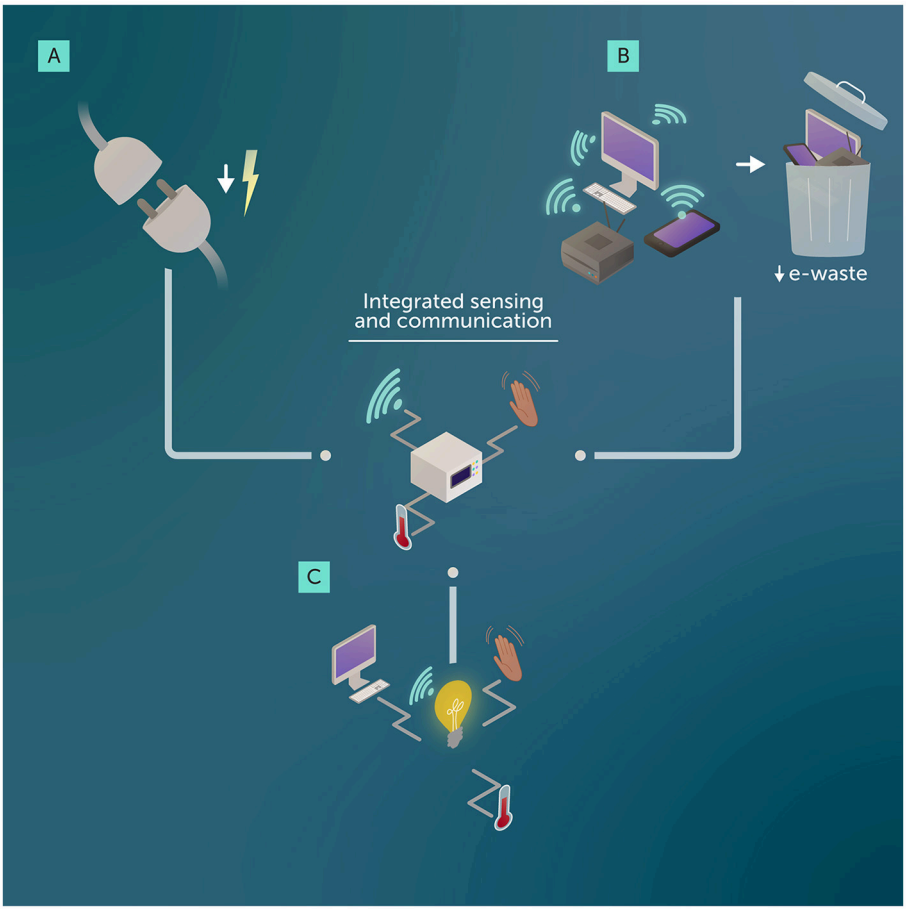

Figure 1

By combining the sensing and communication functions of networks into one system, ISAC has many potential applications. **(A)** Through smart grids, ISAC could improve how electricity is delivered and used, increasing reliability. Using fewer, more efficient devices could also save energy. **(B)** ISAC could reduce device clutter which, in addition to speeding up networks, could help reduce the amount of dangerous e-waste produced. **(C)** Optical wireless technology, which uses light to send information, could be used in smart lightbulbs that brighten the room while also sensing the environment and helping devices talk to each other.

OPTICAL-WIRELESS TECHNOLOGY

A system that uses light, instead of radio waves, to send and receive information, avoiding interference and working in places like hospitals or factories.

One area where ISAC stands out is **optical-wireless technology**, which uses light instead of radio waves to send and receive information [4]. For example, imagine a smart lightbulb in your home. Along with

brightening your room, this lightbulb could also help devices like your phone or computer "talk" to each other, and even sense things in the environment, like air temperature or if someone is moving around. Optical-wireless systems are especially useful in places like hospitals or factories, where regular wireless signals, like Wi-Fi, might interfere with sensitive equipment such as medical machines or industrial sensors. In hospitals, illuminated panels in patient rooms could provide light while also monitoring patient movement or vital signs. With ISAC, these panels could communicate directly with medical equipment, eliminating the need for extra sensors and making care more efficient and more comfortable for patients. By using light instead of radio waves, optical-wireless technologies avoid interference and work smoothly in these challenging environments.

ISAC also shows promise in environmental monitoring, agriculture, and energy systems. For instance, in environmental monitoring, ISAC sensors could track air quality, detect pollution, or measure changes in water levels, helping communities respond to environmental challenges. In **smart agriculture**, ISAC systems could go beyond simply measuring soil moisture. Sensors could map an entire field, showing farmers exactly where water or fertilizer is needed most. This saves resources and time, reduces waste, and helps farmers grow healthier crops. In energy systems, ISAC could improve how electricity is delivered and used. Modernized electrical networks called **smart grids** could use ISAC to monitor energy use, detect problems like overheating or damage to power lines, and respond quickly to changes in the demand for electricity. Sensors could send instant alerts to repair crews, reducing the length of power outages and improving reliability.

SMART AGRICULTURE

The use of technology to help farmers work more efficiently, like sensors that monitor crops and show exactly where water or fertilizer is needed.

SMART GRIDS

Modern energy networks that use sensors and communication tools to monitor electricity, detect problems, and make energy use more reliable.

BIG CHALLENGES, BIGGER OPPORTUNITIES

ISAC has the potential to transform how we connect and use technology, but it is still a work in progress. One big challenge is figuring out how to combine sensing and communication into a single system without slowing it down or making it too complicated. Traditionally, sensing and communication have been separate because they require different types of signals and hardware—sensing often involves detecting tiny details in the environment, while communication focuses on quickly transmitting data. Merging these two functions without interference or loss of accuracy is difficult and requires smarter programs, smarter signals, and better equipment to help ISAC do both jobs quickly and accurately.

Another challenge is making sure ISAC systems can work together. Right now, different companies design sensors and devices in their own unique ways, which can cause problems when they need to share information. For example, in a smart city, traffic sensors with ISAC technology need to communicate smoothly with cars, streetlights,

and buses. If they cannot work together, the whole system could fail. Clear rules and standards are needed to make sure everything runs smoothly.

Despite these challenges, ISAC is highly promising. By combining sensing and communication, ISAC could save energy, reduce the number of devices we need, and make networks faster and more efficient. In contrast, keeping sensing and communication separate means more hardware, higher costs, and slower responses in uses like self-driving cars or smart power grids. With more research and development, ISAC could become a key part of the future of wireless systems.

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CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

HARRY
I am Harry. I enjoy a wide range of sports and games, and I am extremely interested in the different fields of science, especially biology and the biomedical sector, where I can see how applications of biochemistry and genetics are able to effectively solve real world problems!

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Mohamed-Slim Alouini was born in Tunis, Tunisia. He earned his Ph.D. from the California Institute of Technology (Caltech) in 1998 before serving as a faculty member at the University of Minnesota and later at Texas A&M University at Qatar. In 2009, he became a founding faculty member at King Abdullah University of Science and Technology (KAUST), where he currently is the Al-Khawarizmi Distinguished Professor of Electrical and Computer Engineering and the holder of the UNESCO Chair on Education to Connect the Unconnected. Dr. Alouini is a Fellow of the IEEE and OPTICA and his research interests encompass a wide array of research topics in wireless and satellite communications. He is currently focusing on addressing the technical challenges associated with information and communication technologies (ICT) in underserved regions and is committed to bridging the digital divide by tackling issues related to the uneven distribution, access to, and utilization of ICT in rural, low-income, disaster-prone, and hard-to-reach areas. *slim.alouini@kaust.edu.sa

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