The Scanning the Literature column provides concise summaries of selected papers that have recently been published in the field of networking. Each summary describes the paper's main idea, methodology, and technical contributions. The purpose of the column is to bring the state of the art of networking research to readers of *IEEE Network*. Authors are also welcome to recommend their recently published work to the column, and papers with novel ideas, solid work, and significant contributions to the field are especially appreciated. Authors wishing to have their papers presented in the column should contact the editor.

Xiaohua Tian, Shanghai Jiao Tong University
xtian@sjtu.edu.cn

A notable development of wireless networks in the last decade is that the network is being transformed from the pure communication infrastructure into a smarter platform that is capable of smart sensing. It has been verified that wireless signals, if smartly exploited, can reveal much information on the environment, such as the wireless terminal's location, people's actions, and even the nature of materials found there. Such magical functions lay the foundation for a smarter wireless network that could provide more ease to users. The column in this issue focuses on the state of the art of smart sensing. We particularly introduce how to use wireless network infrastructures to realize target imaging, 3D skeleton, localization, fall detection, and through-the-wall detection.

Target imaging and material identification play an important role in many real-life applications. The key intuition is that different materials and target sizes cause different amounts of phase and received signal strength (RSS) changes when RF signal penetrates the target. However, multiple challenges need to be addressed before we can turn the idea into a functional system. In the following paper, Wang *et al.* try to solve these problems with their design.

TagScan: Simultaneous Target Imaging and Material Identification with Commodity RFID Devices

Ju Wang, Jie Xiong , Xiaojiang Chen, Hongbo Jiang, Rajesh Krishna Balan, Dingyi Fang, P*roc. MobiCom*, Snowbird, Utah, USA, Oct. 16–20, 2017.

This paper introduces TagScan, a system that can identify the material type and image the horizontal cut of a target simultaneously with cheap commercial off- the-shelf (COTS) RFID devices. The authors propose solutions to all the challenges and evaluate the system's performance in three different environments. TagScan is able to achieve higher than 94 percent material identification accuracies for 10 liquids and differentiate even very similar objects such as Coke and Pepsi. TagScan can accurately estimate the horizontal cut images of more than one target behind a wall.

Previous works have shown that RF signals carry an impressive amount of information about people and their movements. For example, novel algorithms have led to accurate localization within tens of centimeters, and advanced sensing technologies have enabled people tracking based on the RF signals that bounce off their bodies. However, how rich a description of people can one extract from the surrounding radio signals? In the following paper, Zhao *et al.* introduce their system, which infers 3D human skeletons from RF signals.

RF-Based 3D Skeletons

Mingmin Zhao, Yonglong Tian, Hang Zhao, Mohammad Abu Alsheikh, Tianhong Li, Rumen Hristov, Zachary Kabelac, Dina Katabi, Antonio Torralba, *Proc. SIGCOMM*, Budapest, Hungary, Aug. 20–25, 2018.

This paper introduces RF-Pose3D, the first system that infers 3D human skeletons from RF signals. It requires no sensors on the body, and works with multiple people and across walls and occlusions. Further, it generates dynamic skeletons that follow people as they move, walk, and sit. As such, RF-Pose3D provides a significant leap in RF-based sensing and enables new applications in gaming, healthcare, and smart homes. RF-Pose3D is based on a novel convolutional neural network (CNN) architecture that performs high-dimensional convolutions by decomposing them into low-dimensional operations. This property allows the network to efficiently condense the spatiotemporal information in RF signals. For each individual, it localizes and tracks their body parts: head, shoulders, arms, wrists, hips, knees, and feet. The evaluation results show that RF-Pose3D tracks each keypoint on the human body with an average error of 4.2 cm, 4.0 cm, and 4.9 cm along the X, Y, and Z axes, respectively. It maintains this accuracy even in the presence of multiple people, and in new environments that it has not seen in the training set.

Decimeter-level localization has become a reality, in part due to the ability to eliminate the effects of multipath interference by directly measuring geometric features of the line of sight (LoS) signal, such as angle of arrival (AoA) or time of flight (ToF). However, due to fundamental limits in clock synchronization or range resolution, current methods require some form of explicit coordination between nodes. Coordination between nodes can take many forms but cannot be achieved without introducing complexity, communication overhead, pre-deployed infrastructure, and/or the practical challenges of protocol rollout and adoption. To solve these problems, Soltanaghaei *et al.* illustrate their design in the following paper.

Multipath Triangulation: Decimeter-Level WiFi Localization and Orientation with a Single Unaided Receiver

Elahe Soltanaghaei, Avinash Kalyanaraman, and Kamin Whitehouse, *Proc. MobiSys*, Munich, Germany, June 10–15, 2018.

In this paper, the authors present multipath triangulation, a new localization technique that uses multipath reflections to localize a target device with a single receiver that does not require any form of coordination with any other devices. In this paper, the authors leverage multipath triangulation to build the first decimeter-level WiFi localization system, called MonoLoco, that requires only a single access point (AP) and a single channel, and does not impose any overhead, data sharing, or coordination protocols beyond standard WiFi communication. As a bonus, it also determines the orientation of the target relative to the AP. The authors implemented MonoLoco using Intel 5300 commodity WiFi cards and deployed it in four environments with different multipath propagation. Results indicate median localization error of 0.5 m and median orientation error of 6.6 degrees.

Falls are the leading cause of fatal and nonfatal injuries to the elderly in modern society. According to the Centers for Disease Control and Prevention, one out of three adults aged 65 and over falls each year. Most elderly people are unable to get up by themselves after a fall, and studies have shown that the medical outcome of a fall is largely dependent on the response and rescue time. The delay of medical treatment after a fall can increase the mortality risk in some clinical conditions. To solve this problem, Wang *et al.* show their fall detection system in the following paper.

RT-Fall: A Real-Time and Contactless Fall Detection System with Commodity WiFi Devices

Hao Wang, Daqing Zhang, Yasha Wang, Junyi Ma, Yuxiang Wang, Shengjie Li, *IEEE Transactions on Mobile Computing*, vol. 16, no. 2, pp. 511–526, Feb. 2017.

This paper presents the design and implementation of RT-Fall, a real-time, contactless, low-cost but accurate indoor fall detection system using the commodity WiFi devices. RT-Fall exploits the phase and amplitude of the fine-grained channel state information (CSI) accessible in commodity WiFi devices, and for the first time fulfills the goal of segmenting and detecting the falls automatically in real time, which allows users to perform daily activities naturally and continuously without wearing any devices on the body. Experimental results in four indoor scenarios demonstrate that RT-fall consistently outperforms the state-of-the-art approach WiFall with 14 percent higher sensitivity and 10 percent higher specificity on average.

Being essential for device-free applications, device-free human detection has gained increasing interest, of which through-the-wall (TTW) human detection is a great challenge. Existing TTW detection systems either rely on massive deployment of transceivers or require specialized WiFi monitors, making them inapplicable for real-world applications. Recently, more and more researchers have tapped into the physical layer for more robust and reliable human detection, ever since CSI has been able to be exported with commodity devices. Despite great progress achieved, there have been few works studying TTW detection. To fill this gap, Zhu *et al.* illustrate their detection scheme in the following paper.

R-TTWD: Robust Device-Free Through-The-Wall Detection of Moving Human With WiFi

Hai Zhu, Fu Xiao, Lijuan Sun, Ruchuan Wang, and Panlong Yang, *IEEE Journal on Selected Areas in Communications*, vol. 35, no. 5, pp. 1090–1103, May 2017.

In this paper, the authors propose a novel scheme for robust device-free TTW detection (R-TTWD) of a moving human with commodity devices. Different from the time dimension-based features exploited in previous works, R-TTWD takes advantage of the correlated changes over different subcarriers and extracts the first-order difference of eigenvector of CSI across different subcarriers for TTW human detection. Instead of direct feature extraction, the authors first perform PCA-based filtering on the preprocessed data, since simple low-pass filtering is insufficient for noise removal. Furthermore, the detection results across different transmit-receive antenna pairs are fused with a majority-vote-based scheme for more robust and accurate detection. The authors prototype R-TTWD on commodity WiFi devices and evaluate its performance both in different environments and over a long test period, validating the robustness of R-TTWD with detection rates of both moving human and human absence over 99 percent regardless of different wall materials, dynamic moving speeds, and so on.

Backscatter communication is well known for providing an ultra-low-power wireless link for connecting Internet of Things devices. It only consumes microwatts of power during data transmission because it passively reflects and modifies wireless signals to embed information, instead of doing active transmission like WiFi. However, it requires a dedicated infrastructure of expensive custom hardware (e.g., RFID readers). Hence, despite their power efficiency, we actually do not see wide deployment of backscatter-based systems. As a result, researchers have recently been exploring using already deployed commodity radios, such as WiFi and Bluetooth, to act as the excitation radio and/or receiver. In the following paper, Zhang *et al.* propose a commodity-radio-based backscatter system.

FreeRider: Backscatter Communication Using Commodity Radios

Pengyu Zhang, Colleen Josephson, Dinesh Bharadia, Sachin Katti, *Proc. CoNEXT*, Seoul/Incheon, South Korea, Dec. 12–15, 2017.

The authors introduce the design and implementation of FreeRider, the first system that enables backscatter communication with multiple commodity radios, such as 802.11g/n WiFi, ZigBee, and Bluetooth, while these radios are simultaneously used for productive data communication. The key technique used by FreeRider is codeword translation, where a tag can transform a codeword present in the original excitation signal into another valid codeword from the same codebook during backscattering. In other words, the backscattered signal is still a valid WiFi, ZigBee, or Bluetooth signal. Therefore, commodity radios decode the backscattered signal and extract the tag's embedded information. More importantly, FreeRider does codeword translation regardless of the data transmitted by these radios. Therefore, these radios can still do productive data communication. The authors built a hardware prototype of FreeRider, and the empirical evaluations show a data rate of ~60 kb/s in single tag mode, 15 kb/s in multi-tag mode, and a backscatter communication distance of up to 42 m when operating on 802.11g/n WiFi.