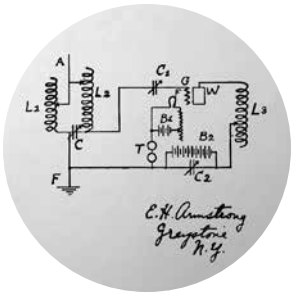
MAN OF HIGH FIDELITY

EDWIN ARMSTRONG

ALUMNUS AND FORMER FACULTY

One warm, summer night in 1912, a Columbia Engineering student named Edwin Howard Armstrong, about to enter his senior year, made a momentous discovery. At his home in Yonkers, later designated a National Historic Landmark, Armstrong had built the regenerative circuit, which would forever change long-distance communications.

Armstrong's new circuit, patented in 1914, fed radio signals back through an audion circuit to reinforce themselves. His innovation not only greatly amplified signals, but the positive feedback made the circuit an "oscillator" capable of transmitting its own signal. In one masterstroke, Armstrong made radio practical, the first in an *[continued on page 32]*



Professor Gil Zussman and undergraduate student Ben Zhu set up an experiment in a testbed composed of EnHANTs prototypes.

Sidebar, top: Portrait of Edwin H. Armstrong (University Archives); *bottom*: feed-back circuit drawing

GIL ZUSSMAN

COMMUNICATIONS

MAKING THE CONNECTION

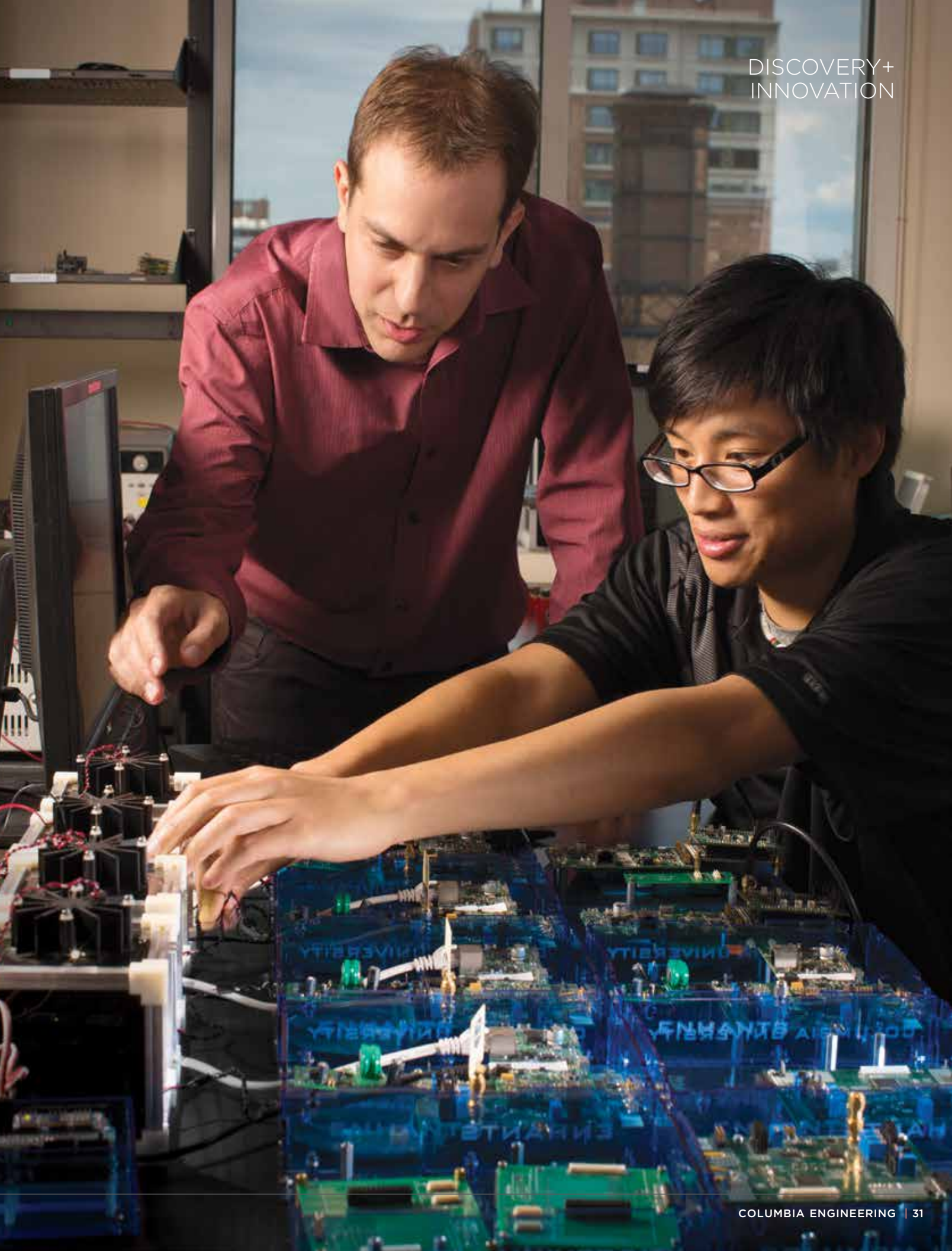
On any given day, the first thing most of us do is rev up our mobile device of choice: smartphone, laptop, tablet, or smart watches. Then they all magically sync together. The future of interconnectedness is quickly moving beyond just popular gadgets into wirelessly connecting even everyday objects. Gil Zussman, associate professor of electrical engineering, has devoted his research to exploring the continuing evolution of these advanced wireless networks.

Following the 1990s Internet boom, a wireless and mobile networking transformation began. Now, networks such as cellular, wireless, local area, sensor, and vehicular are continually being enhanced and deployed.

"These wireless networks found numerous applications in diverse areas such as broadband access, military operations, health care, supply chain management, and public safety, and in general, the wireless revolution has already transformed the way we communicate," Zussman says.

Zussman studies the ever-changing wireless networking technologies and their related challenges, which include interference during simultaneous transmissions, limited capacity on the wireless channel, mobility, and battery life constraints on the devices. As a simple example of the first-mentioned challenge, interference,

Zussman's research is central to the Energy Harvesting Active Networked Tags (EnHANTs) Project at Columbia, a collaboration among several Engineering professors who are developing novel hardware, algorithms, and software to actively track everyday items otherwise not tracked, such as books, furniture, toys, keys, clothing, and even food.



EDWIN ARMSTRONG

[continued from page 30]
extraordinary string of historic breakthroughs during four decades at Columbia.

Armstrong stayed on after graduating in 1913, working as an assistant to the legendary Michael I. Pupin 1883CC, cofounder of the Electrical Engineering Department 25 years before. Pupin secured him access to the Marcellus Hartley Laboratory in the basement of Philosophy Hall, where Armstrong was to make many more advances.

During World War I, while serving in France in the Army Signal Corps, Armstrong again revolutionized radio by developing the superheterodyne receiver, the basis for modern reception technology. He earned the rank of major and conducted experiments from the Eiffel Tower.

Returning to Columbia Engineering as assistant professor, flush from his inventions, Armstrong turned down a salary to focus exclusively on research. He developed the super-regenerative receiver, refining his earlier work, and turned to the puzzle of reducing static in radio signals. After 10 years of feverish research, he engineered wideband FM radio in the early 1930s. Beset by a long series of dubious lawsuits, however, Armstrong spent much of the rest of his life fighting for credit and just compensation. He died in 1954.

Without the legal battles that consumed his later years, there's no telling what else Armstrong could have achieved, but the judgment of history is clear. His preeminence earned him a U.S. postage stamp in 1983, and Columbia's Armstrong Hall bears his name.

AP	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1		_	100	0	100	23	100	_	_	93	96	76	99	_	95	100	100	100	_	_
2	_	99	_	100	0	_	_	_	100	100	_	98	55	_	98	_	66	94	_	_
3	100	_	_	99	_	_	100	_	0	100	99	95	_	_	98	97	98	_	100	_
4	_	100	_	_	_	_	100	97	87	_	_	98	_	_	98	_	98	_	100	95
5	_	100	99	_	_	_	_	99	100	_	_	98	_	88	_	_	3	72	79	_
6	_	99	99	_	_	_	100	99	_	_	_	_	_	_	_	_	58	59	98	99
7	100	_	_	_	_	100	_	30	_	_	86	99	98	_	_	97	98	_	_	_
8	_	_	_	_	99	100	99	_	20	100	100	91	_	_	0	41	64	_	0	_
9	_	_	_	_	99	66	_	_	86	93	_	_	_	_	_	93	_	60	_	_
10	87	98	_	100	67	_	_	98	_	_	_	94	_	99	_	96	97	_	_	_
11	_	_	29	_	99	100	_	11	_	89	_	_	_	97	_	80	98	_	_	30
12	_	_	_	99	_	98	_	_	93	_	98	_	_	_	_	88	_	0	_	_
13	_	_	100	96	_	_	_	_	_	98	92	2	_	98	_	43	_	_	0	_
14	_	_	_	_	_	99	_	_	_	58	_	_	_	_	_	_	93	0	_	_
15	_	100	_	_	_	_	99	_	_	_	_	_	87	98	_	_	_	_	0	_
16	_	_	63	_	_	_	0	0	_	_	65	_	_	98	_	_	_	55	_	_
17	_	_	0	_	_	78	35	_	79	16	93	36	_	_	31	_	88	0	_	44
18	_	_	_	_	59	_	_	_	99	71	93	_	_	0	54	25	_	_	_	_
19	_	_	96	_	0	98	99	_	_	0	7	_	_	100	_	_	_	_	_	_
20	_	_	_	_	_	_	_	_	96	_	78	_	98	_	_	_	_	_	_	_
PDR	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100

A WiMAX base station (on top of the Mudd Building) used for hands-on experimentation in Electrical Engineering and Computer Science networking classes.

Top, left: Packet delivery ratios to various nodes in an experiment in a large-scale WiFi testbed; *right*: EnHANTs prototypes

Zussman explains that if you have a set of wireless device users simultaneously communicating with each other, unless they decide who transmits when, in many instances the transmitters will collide. In that case, no one will get anything. However, according to Zussman, devices that employ clever algorithms can achieve high throughput.

That's what Zussman, director of Columbia's Wireless and Mobile Networking (WiMNet) Lab, and his team of researchers and students zero in on. They tackle the networking challenges by focusing on developing architectures and algorithms that run across multilayered network protocol stacks.

"We aim to provide a sound theory for real systems by dealing with wireless and mobile networking problems that have a strong grounding in reality and by obtaining a fundamental understanding of these problems," Zussman says.

The WiMNet Lab has aligned itself with the likes of IBM Research, AT&T Labs Research, and Alcatel Lucent Bell Labs.

"We've been collaborating with them mostly on scheduling problems with either WiFi or cellular networks, thinking about how to develop the scheduling

algorithms for the next generation," Zussman says. He went on to explain that most of the collaborations are within the research arms of those companies. "The main idea is to collaborate with very talented researchers and to try to develop solutions that they will be able to internally market to their R&D or product teams."

Another major part of Zussman's research focus is the Internet of Things, or the seamless interconnectedness of computing devices within the Internet stratosphere—specifically, within the Energy Harvesting Active Networked Tags (EnHANTs) Project, a collaboration among the research teams of several Columbia Engineering professors, including Professors Peter Kinget, Ioannis (John) Kymissis, Dan Rubenstein, and Luca Carloni. The project team has been developing novel hardware, algorithms, and software to actively track everyday items otherwise not tracked, such as books, furniture, toys, keys, clothing, and even food. EnHANTs will be small, flexible, self-reliant tags that can be attached to any object to determine its location in cases of natural disasters, physical moves, or simple misplacement of belongings. Most recently, the team has been conducting measurements of harvested energy availability, developing harvesting-aware algorithms, and prototyping EnHANTs.

Following the 1990s Internet boom, a wireless and mobile networking transformation began. Now, networks such as cellular, wireless, local area, sensor, and vehicular are continually being enhanced and deployed.

Zussman cited a library, a grocery store, a courier truck, and a warehouse as real-life examples of where and how these small, self-powered, networked tags could replace scanning of bar codes and potentially make items and merchandise self-organizing.

"Imagine you put these tags on the outside cover of every book in a library, and the tags start harvesting the indoor light energy and communicating with each other," Zussman suggests. Further illustrating this example, Zussman explains that if a math book has been erroneously placed in the literature section of the library, its tag could figure it out by communicating with its new neighbors. Then, the tag can alert the librarian via the network and an LED light on the misplaced book would help the librarian spot it on the wrong shelf.

Zussman's own interest in wireless networking research was spurred by the dot-com bust that occurred right after he started his PhD studies.

"The area that was interesting for me was using analytical tools I was very familiar with to solve problems in the real world, and my sense, at that time, was that wireless was the next big thing in networking," he says.

Indeed, wireless networking continues to rapidly evolve due, in part, to the discoveries of Zussman, together with his students and postdocs.

By Janet Haney