Summary of *Enabling Deep-Tissue Networking for Miniature Medical Devices, SIGCOMM '18*

The paper introduces In-Vivo Networking (IVN) system which overcomes the challenges of powering up and communicating with miniature sensors implanted or injected in deep animal tissues. There are three key challenges IVN is facing: 1) RF signals experience exponential attenuation when they propagate through the human body, which reduces the power gain delivered to in-vivo sensors significantly; 2) the size limitation of the antennas attached to miniature medical devices causes extremely low power harvesting efficiency; 3) IVN receives no channel feedback from its battery-free sensors, so many traditional beamforming algorithms such as MIMO are not feasible. To overcome these challenges, the paper presents a new beam forming algorithm called Coherently-Incoherent Beamforming (CIB) which is able to power up in-vivo sensors without prior channel information.

CIB contains two main properties: 1) the communication process is coherent, indicating all antennas transmit commands synchronously; 2) antennas incoherently transmit different frequencies to create a time-varying channel. The paper introduces the problems with RF power harvesting in deep tissues and explains how CIB resolves them with its novel design. In general, RF power harvesting requires the battery-free sensors to convert the RF signal to direct current. However, practical energy harvester experiences significant performance drop due to the diode threshold effect. The properties of CIB give potentials to overcome the threshold voltage through the constructive interference of different frequencies. They also indicate that CIB can power up sensors at different locations in 3D space using the same set of frequency combinations. The paper further talks about impacts of frequency selection and the formula they use to achieve optimal power gain.

During the class discussion, we focused on the design of IVN, analyzed CIB's basic formulation and the possibilities of overcoming the threshold limit, and questioned some of its implementation details and evaluation results.

We agreed that in showing how RF-DC energy harvester work, the paper gives a very clear explanation which accessible to readers without EE background, but the follow-up descriptions about voltage threshold arises confusion due to its scattered structure. We discussed and questioned the efficiency of CIB algorithm, since it achieves constructive power gain intermittently and harvest only when interfered frequency is above the threshold, which is less efficient comparing to traditional methods. We also noticed some problems in its frequency selection scheme. First, they choose a random initial phase for each frequency to emulate blind channel condition. However, we believed they should keep the initial phase same for all frequency in order to only measure the impact of arbitrary frequency combination. Second, the paper mentions specific harvesting challenges in deep tissues. The reflection of RF signals at the air-tissue boundary and exponential attenuation loss due to propagation through human tissues reduce the power gain to in-vivo sensors, along with the limitation of miniature antenna size that is proportional to the amount of energy harvest. However, in the objective function they use to optimize the power gain, none of the above factors are included.

We found some unclear descriptions in their observation and evaluation sections which may arise other readers' confusions. The paper concludes that IVN can power up millimeter-sized battery-free sensors at depth of 11cm in liquid, and it also demonstrates IVN can charge and communicate with a deep-tissue sensor placed in a living pig's stomach. Considering the testing pig is 85kg, the difficulty should be much higher in such multiple layer animal tissues comparing to pure liquid, so the results should not be better than 11cm while we suspect a 85kg pig's stomach is deeper than that. We guessed their successful result uses standard tags rather than miniature tags, because another section reports all tests are failed in such case. Furthermore, their evaluation of CIB include comparing power gain with other methods, but its lack of information arises our confusion about what it is comparing to. We discussed and figured out the most possible answer is that they compare power gain of CIB using N antennas to that using 1 antenna, rather than comparing CIB with traditional methods both using N antennas. In conclusion, although this paper could improve in many ways mentioned above, we agree it proposes a valuable work in deep-tissues networking and demonstrates a great potential for further improvement.