Track III: Micro-sphere (swarm) wireless networks for joint communication, localization and enforced movement

We consider a dense network of hundreds or thousands of sub-mm size sensors/actors. These nodes (tags) have extremely low complexity and are powered wirelessly (i.e. operate in an RFID-like fashion). The nodes are smart, i.e. they comprise some electronics of limited complexity. The network is highly asymmetric, there may be one or more external high complexity nodes (readers) complementing the swarm of tags. Our goals are fivefold: (i) wirelessly supply power to the tags, (ii) enable communication in between the nodes and between nodes and readers, (iii) localize the nodes with respect to each other and in a global coordinate system with sub-mm accuracy, (iv) intentionally generate directed forces to specific nodes in order to initiate a specific movement (e.g. in order to make a subset of nodes move closer, or to orient a subset of nodes in a specific direction) and (v) implement a specific energy absorption profile in the swarm (this feature can be used to generate a location specific temperature profile such as required by thermal tumor therapy). A system of this type has applications in such diverse fields as medical diagnosis and therapy, smart matter, physics, measurement and biology (swarm behavior) to name a few.

In a dense swarm type setting the nodes will be at sub-mm distance. For this reason the localization techniques known from large scale systems (such as ToA) have limited applicability. Due to the small form factor of the nodes it is difficult to wirelessly supply power to them and we may have to resort to node cooperation to achieve data rates of practical relevance. The generation of directed force and swarm energy absorption profile in a communication network is a novel requirement in our context.

As the small form factor of our network prevents the use of traditional localization techniques such as Time-of-Arrival or Angle-of-Arrival and multi-lateration, we currently focus on a magnetic near-field approach. With it our communication and power supply problem at first glance appears similar to standard RFID. Nonetheless there are major differences: (i) the small form factor diminishes the power transferred to the tags, (ii) we require communication between the tags, and (iii) a huge number of tags may be collocated within reader range. Thus we need new, possibly cooperative, communication techniques that enable inter-tag communication and minimize the sum power required for communication. One promising approach for relative localization is the measurement of the magnetic coupling between the tags and between tags and reader. Following the asymmetric structure of our system we focus on localization techniques that put most of the complexity burden on the reader side. It may be helpful however to have the tags execute some predefined sequence of actions such as a variation of the terminal impedance of the tag coil. The energy absorption profile of the tag swarm can as well be varied by modifying the terminal impedances of the tags. Alternatively we can rotate each tag with respect to the reader field in order to adjust the magnetic flux and thus the energy absorbed. In principle it is possible to use the power absorbed by each tag to generate a DC-current in the tag coil. Either in conjunction with an external DC magnetic field or with the fields generated by other tags we can apply a force to a specific tag.

From our initial work on localization in Fig. 1 we show the cumulative density function (CDF) of the localization error in an experiment at 25MHz, which comprises five anchors and one agent. All nodes are placed in a 50x50cm^2 square. The estimation of the random agent position is based on impedance measurements in all anchors. All nodes have circular coils with a diameter of 2.5cm. For the green and red curve we have applied a simple and fast auto-calibration step prior to the experiment. Note the excellent accuracy achieved with calibration (median: 1-1.5mm ).
Figure 1: Empirical Cumulative Density Function (CDF) of the positioning error in a localization systems with passive agents, which is based on impedance measurements and magnetic near-field coupling.