Epidemic-Style Information Dissemination in Large-Scale Wireless Networks

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Over the years, advances in technology have made it possible to dramatically reduce the size and cost of computers, making them ubiquitous in the home and at the office. Furthermore, the continued miniaturization of processing units has given rise to embedded systems, just as powerful as personal computers of a few years ago. These special-purpose computer systems can be found anywhere from mobile phones to kitchen appliances and it is not unreasonable to think that their numbers will increase in coming years.

While personal computers are often networked by means of a fixed infrastructure of routers and switches, smaller computing devices usually use the wireless spectrum to connect to the infrastructure. These devices act as a wireless extension of the wired network. In order for these wireless devices to form their own autonomous wireless network, without relying on the services provided by the infrastructure, many challenges have to be addressed. In this dissertation, we focus on how to disseminate information effectively and efficiently in these purely wireless networks.

The characteristics of the wireless medium (limited range of the radios, unreliable communication, dynamic topologies) complicate the use of centralized solutions for anything other than small deployments. While centralized solutions might work well in a small setting (such as a group of users with laptops in a coffeeshop), we envision that the ubiquity of wireless embedded systems will lead to the possibility of having large-scale wireless networks in the order of thousands of nodes. For these networks, centralized administration would be anything but trivial. What large-scale wireless networks require is algorithms that are fully

distributed, adaptive to changing conditions, resilient to failures of individual elements, and based on local interactions. Epidemic (or gossip) algorithms fulfill these requirements.

The terms *gossip* and *epidemics* are generally used interchangeably. Formally, gossiping is a subgroup of epidemic protocols. Analogous to rumor spreading in real life, gossiping means that a rumor is spread when entities interact. This interaction occurs at random and each time the rumor is communicated, the receiving entity will spread it further with a certain probability. This results in the rumor being spread rapidly, but without any hard guarantees that it will reach all entities. In computer systems, a gossip protocol generally refers to a protocol with the following characteristics: random peer selection, periodic execution and symmetry (meaning that the same algorithm is executed by all nodes).

We have explored two basic types of gossip protocols: one based on peer-to peer interactions (called the shuffle) and one based on broadcast communication (called SharedState). While the style of communication (request/reply vs. broadcast) differs between both protocols, they share many characteristics: periodic execution, limited storage space and fixed amount of data exchanged. For both protocols, we conducted an extensive study of the characteristics of the dissemination in large-scale networks and how these characteristics are affected by different parameter settings and design choices. After an extensive simulation study and analysis, we can summarize the lessons we have learned as follows:

- A network of gossiping nodes displays certain large-scale behavior after repeated execution of the gossip routines. While changes to the routines that describe the local interactions often result in changes in the large-scale behavior, the mapping between changes in small-scale interactions and their large-scale implications is not obvious.

- Identifying the parameters that affect system behavior is crucial, yet not trivial, as protocols may be sensitive to changes in some parameters more than others. By restricting our protocols to a particular framework, we have reduced the parameter space. We find that, even when dealing with a reduced parameter space, the setting of the parameters still remains an open question. Not only is the effect of a given parameter setting not easily predictable, there may be non-obvious dependencies between parameters.

- While random behavior is a key ingredient of gossip protocols, it important to identify how and when to best apply it. Throughout our work, we have strived to find the balance between retaining the random component of gossiping and improving performance. Although the protocols for information dissemination we consider are simple, there are several points at which decisions have to be taken. To rely on randomness at every step of the decision-making process would produce less than optimal results.

Based on these observations, we conclude that although gossip protocols can be very simple to implement, obtaining the desired large-scale behavior is far from simple. To truly understand the mechanics of gossip, followed two approaches: a) we explored a variety of parameter and design choices and b) modelled the interactions between gossiping nodes. The first approach required us to evaluate the performance of the protocol whenever changes were introduced to determine if the changes were an improvement, giving us a good idea of what works or not. The second approach forced us to understand the gossip interactions at a deeper level, evaluate and even reconsider certain design decisions. A combination of both approaches is key to understanding how to design and fine-tune a gossip protocol to obtain the desired large-scale behavior.