Pervasive Computing powered by cell phones and opportunistic networking

White Paper by Mohan Kumar, The University of Texas at Arlington

Background and experience:

Kumar started research in Pervasive Computing in 2001. He was the lead PI in an NSF funded project on the development of middleware for pervasive environments, started in 2002. Subsequently, has been a PI (2) or co-PI (2) in four projects on topics in pervasive computing, funded by the NSF(3) and the Air Force Research Labs (totaling approx. $3M). The major outcomes of these projects include: i) development of adaptive middleware (PICO) for pervasive environments; ii) development of a seamless service composition (SeSCo) mechanism that handles node mobility, heterogeneity and reliability; iii) middleware for node selection in sensor systems (MidFusion); iv) middleware support for sensor systems; v) architecture and algorithms to support collaborative virtual observation in dynamic systems; vi) architecture to support adaptive context reasoning in heterogeneous multi-context systems; vii) a scheme for optimal service replication in opportunistic networks; viii) a scheme for mutual exclusion in opportunistic computing; ix) schemes for authentication and trust in pervasive systems; and others under development. He has published more than 50 refereed articles in journals and conference proceedings and supervised 8 PhD dissertations in the broad area of pervasive computing. In addition, Kumar is a cofounder of the IEEE International conference on Pervasive Computing and a founding editor of the Elsevier's Pervasive and Mobile Computing Journal. He served as the program chair of PerCom 2003, General Chair, PerCom 2005; and Steering Committee Chair (PerCom2007-2010). He served as a co-chair of the NSF/EU Workshop on Pervasive Computing and Social Networking in Mannheim, Germany on March 29, 2010.

Vision:

The future of pervasive computing at large scale lies in the exploitation of ubiquitous cell phones and opportunistic networks involving cell phones and other devices. It is obvious that the cell phone is gradually turning into a multipurpose versatile device that will be used for computing, document creation, Internet browsing, environment sensing, health monitoring and so on. Today, there are more than 4 Billion cell phone users worldwide; at least 1 Billion of them possess powerful CPUs (each capable of several MIPS), multiple radios, Gbytes of memory, embedded sensors etc. These devices are carried by people who are gregarious by nature, giving rise to billions of opportunistic contacts at any given time. People's social activities lead to the creation of opportunistic paths and networks. While the cell phone is used widely in many applications today, utilization of the collective power of large numbers of cell phones is an area in its infancy, but with tremendous potential. Ubiquitous, multifunctional cell phones carried by users make opportunistic contacts with other cell phones, sensors (embedded on vehicles, on physical infrastructure), RFIDs on objects, and others. Creation and maintenance of distributed computing environments on top of opportunistic networks created through cell phones is the key to new pervasive applications that utilize hundreds or thousands of devices.

Evidence that pursuing this vision will lead to major advances in the field:

The emergence of participatory sensing over the last few years is a good example of the power and versatility of cell phones carried by users. Indeed, participatory sensing initiatives exploit opportunistic sensing and networking opportunities. Likewise, participatory pervasive application services will emerge in the near future. Cell phones are being utilized in several pervasive applications including health monitoring, GPS-based navigation and others. Furthermore, there is no other platform in the universe that comes even close to that afforded by cell phones and their networks, in terms of numbers. One other vital factor is the advance in wireless communications, in terms of ubiquity and bandwidth. While pervasive computing has emerged as an exciting and high utility field, as prophesied by Mark Weiser to enhance human quality of life, its future lies (especially at scale) in exploiting the most ubiquitous device and creating new application services that can adapt to our social lives.

There are several challenges (from routing packets to user interfaces) to make this vision a reality. Due to limited space, four major challenges are touched upon briefly:

a. Social Context: Adapting to human social life entails understanding social contexts. As users are in the loop (hopefully unobtrusively), their social context determines such vital issues as participation, trust, neighborhood and so on. However, processing low level contexts (from multitude of sources including sensors, applications, humans etc.) and reasoning mechanisms to arrive at high level contexts is a huge challenge. Current context-aware systems are either too specific or confined to local environments. Use of Mobile/Pervasive Clouds for context reasoning is an area of interest. Developing reusable, modular and flexible context processing and reasoning mechanisms that exploit opportunistic networks of mobile cell phones and mobile clouds is another fertile area for future research.
b. Privacy and Trust: Users have always been concerned about their privacy, and rightfully. It is vital to develop anonymization mechanisms that efficiently tradeoff between user privacy and pollution to ensure user effective participation on one hand and reliable services on the other. Trust is a major concern as users will be making their devices available for application tasks (routing, cycle stealing, sensing etc.) that may not even pertain to them. Likewise they will be using virtually unknown devices for their own tasks.
c. Business Models: User and service providers must be incentivized to adopt the opportunistic networking paradigm. New business models are needed to ensure users are appropriately rewarded for making their resources available. Similarly service providers need new business models for allowing users to participate in pervasive applications.
d. Pervasive Cloud: Developing mechanisms to ensure availability and accessibility to cloud computing resources for distributed computations, when needed, through opportunistic networks.

Applications of pervasive computing at scale: Transportation, Entertainment, Marketing, Telemedicine, Sustainability, Safety and security of life and property, Environment monitoring and protection etc.