Mobility Related Issues in Ambient Intelligence Systems

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Abstract

Ubiquitous service and information access to data repositories, sensors, and actuators is becoming more and more included in every day life, for example, by means of personal communication, Wi-Fi access via hot spots, or embedded real-time and automation systems. Ambient intelligence envisions a physical world which is embedded into the virtual world and vice versa.

In order to connect different mobile computing entities, wireless networks operating in infrastructure mode may be utilized, while ad-hoc networks are spontaneously built and adapted to the needs of the dynamically changing environment. Since the dynamics are caused mainly by movements of entities, the modeling of mobility, that is, the movement behavior of an individual or a group, is necessary for capacity planning, for the evaluation of resource allocation algorithms, and for routing approaches. Mobility models may also be used by *mobility aware applications,* for example, predictive algorithms for efficient handover and paging in cellular networks or pro-active parking place allocation.

This leads to three main challenges in mobile wireless networking: mobility modeling, mobile wireless networking while integrating sensors and heterogeneous networks, and mobile information access. This article discusses the applicability of artificial intelligence techniques, in particular software agents and neural networks, to these challenging issues related to mobility research. First, it surveys analytical, heuristically derived and adaptive mobility models. Second, networking issues, such as spontaneous, adaptive and robust wireless networking of small devices like sensors, and goal-driven decisions in the presence of different wireless network service providers are summarized. Third, mobility-awareness in space based and software agent based middleware approaches are discussed. The concept of a *mobility-aware coordination layer* on top of virtual object spaces, developed by one of the authors, is presented.

Introduction

In the early 1990s, Mark Weiser envisioned *ubiquitous computing*, a new way of computing, which enriches the physical world by a multitude of different, mainly very tiny computing entities. Computers become invisible and augment the physical environment everywhere in a networked manner [1][2]. Both work-place scenarios and every-day private living are expected to benefit from embedding digital information into the physical world which enriches and simplifies the interactions with both the physical and virtual environment, everywhere and at any time desired.

Since mobility is an important issue in the field of ubiquitous computing by nature, related problems, for example, seamless roaming between heterogeneous wireless networks, have to be addressed. The following key issues related to mobile computing are based on Satyanaryanan's taxonomy of computer systems research problems in *pervasive computing* (which is often used synonymously to the term ubiquitous computing) [13]:

Mobile networking. How can efficient and robust routing algorithms be applied to ad-hoc networking? If using TCP over wireless networks is disadvantageous, should reliable transmission and synchronous communication be left to the application or handled on middleware layer? How is quality of service modeled on different network layers and which parameters differ significantly compared to fixed networks?
Mobile information access. How can mobility awareness be exploited by middleware approaches in order to support ongoing operations in disconnected states and coordination between distributed processes in the presence of degraded link quality?
Adaptive applications. Which methods are available to introduce fault tolerance and how should the degradation states of the system be modeled? Where and when can proxies be used in order to increase availability and reliability?
Energy aware systems. Since mobile devices rely on a limited power supply, which models can be used to describe power loss? Are there basic and advanced algorithms in order to adapt the system (like disk spin-down)?
Location sensitivity. Which technologies can be used for location prediction? And how accurately do they predict the current location? Is it possible to predict a user's next location based on his historical movements?

Aside from energy awareness, this article addresses selected challenges of every key topic listed above. First, methods for mobility modeling based on analytical models, heuristics and techniques to derive mobility patterns are summarized. More specifically, the application of Markov model based predictors, LZ model based predictors, and the application of statistical analysis techniques and neural networks is discussed. Another section focuses on mobile networking, in particular on protocols and technologies used for wireless sensor networks and on applying agent technology to decision problems among heterogeneous wireless networks. Related to mobile information access and application adaptability, mobility awareness is emphasized in space based and agent based middleware approaches. Furthermore, a *mobility-aware coordination layer* is introduced and the prototype implementation by one of the authors is described.

Modeling Mobility

The roaming behavior of individuals and groups is most interesting in the mobile telecommunications field, in particular, for planning network capacity or for modeling network resource allocation and network load. In ambient intelligence enriched scenarios, mobility patterns may also be used for pro-active location aware applications. For example, a person driving from home to the office will typically follow some similar paths on a daily, weekly, or monthly basis. Assuming such kind of mobility patterns, pro-active location aware applications may select, for example, suitable traffic jam warnings or make parking place reservations in advance.

A *mobility model* is a description of location sequences (including additional parameters, like direction, velocity, acceleration, and a timestamp) describing the motion of an entity in space. From such a model, it is possible to extract *mobility patterns*, which can be compared to *mobility traces*, that is, concrete movement observations from roaming entities. In the context of pro-active applications, mobility models are most useful if they are:

- accurate in terms of agreement between patterns and traces;
- scalable when adding locations and new mobile entities (individuals or resources);
- adaptive by nature, that is, they learn from observing roaming traces;
- inexpensive in terms of computing power and execution time needed.

Analytical mobility models often assume simple model parameters and random movement in order to derive mathematical expressions. Champ et al. [6] give a detailed introduction to a set of commonly used mobility models for ad-hoc networks. The two models most often used are the *Random Walk Mobility Model* and the *Random Waypoint Model*. In the Random Walk Mobility Model, each movement is assumed to be independent of any past location, speed or direction. The Random Waypoint Model proposes random ways, that is, a path between the current location and a randomly chosen next destination. A description of the stochastic properties of this model is presented by C. Bettstetter et al. [7]. Since both models are memory-less, they can generate unrealistic movements in terms of speed, like sudden stops, or in terms of directions, like sudden turns.

Based on selected scenarios, some mobility models have been derived heuristically, like the ETSI test environment [9], which differentiates scenarios in terms of velocity: *Indoor Office*, *Outdoor to Indoor and Pedestrian*, *Vehicular* low speed (120 km/h) and *Vehicular* fast speed (500 km/h). Another classification based on different velocities is described by Ziegert [10], while Markoulidakis et al. [11] reason also about possible locations within three geographical models of different scale: the *City Area Model*, the *Area Zone Model* and the *Street Unit Model*. Jardosh et al. [12] use geographic information about obstacles to restrict the set of possible pathways and to model wireless link transmission restrictions. In order to predict movement, Voronoi diagrams are used and shortest path search is applied.

Song et al. [8] survey and evaluate four major location predictor families (*order-k Markov models*, *Lempel-Ziv (LZ) based models*, *Prediction by Partial Matching (PPM)* and *Sampled Pattern Matching (SPM)*) which predict the next location based on the user movement history and then add it to the user history.

In the order-k Markov case, the prediction of the next location depends on the k most recent locations in the location history. In detail, the location that most frequently followed the current context (that is, the k most recent history locations) is predicted to be the next visited location. For k>2, the effort required for determining transition probabilities rises rapidly ($O(n^k)$, where n denotes the number of possible locations). In practice usually only k≤2 is used, like, for example the mobility patterns derived from Global Positioning System (GPS) traces in the work of Ashbrook et al. [37], or the application of Bayes' Rule to an order-2 Markov model presented by Chan et al.[38]. While new locations (that is, locations that cannot be found in the user movement history) in the basic Markov model are associated with a transition probability zero, in PPM, an unseen location is assigned a positive *Escape Probability*. In SPM, no fixed trace length k is used, but is derived from the longest trace sequence previously identified.

Following LZ algorithm which is based on an incremental parsing algorithm used for text compression by Ziv et al. [14], the user location history *L* is split into sub-location sequences forming a tree. The LZ predictor considers how often an observed sequence *s* can be found in the sequence tree (built by parsing *L*) and calculates the probability for every location *x* by calculating the frequency of occurrence as follows (simplified version; sx denotes the concatenation of s and the next location x):

$$P(nextLocation = x \mid L) = \frac{numberOfOccurrences(sx, L)}{numberOfOccurrences(s, L)}$$

Although LZ based predictors as well as the SPM predictor are more flexible and should perform better than order-k Markov predictors for larger traces, Song et al. [8] identified the 2-order Markov predictor (with a fallback extension in case of occurrence of unseen mobility traces) as the most accurate predictor in an extended study of mobility traces in a campus wireless network. However, when including an aging method (that is, modeling distributions that may change over time and thus describe the observations better), the order-2 Markov predictor performed worst.

Since pattern recognition in mobility traces exhibits important similarities to data mining problems, neural networks may also be applied in this context. Rauber et al. present an advanced *Self-Organizing Map (SOM)* in the research field of text mining [22][23]. The presented *Growing Hierarchical SOM (GHSOM)* may be trained with mobility traces as input patterns. The emerging clusters can be interpreted as the derived mobility patterns.

Another important area with significant connections to the identification and prediction of mobility patterns is information retrieval (an introduction can be found in Berry et a. [35][36]). One of the authors is currently investigating the application of computational linear algebra techniques from that area in the context of predicting mobility patterns. The development of highly efficient numerical techniques for this task will lead to reliable methods, which will be highly beneficial for accurately modelling the mobility behaviour of roaming entities in wireless networks.

Mobile Wireless Networking

Since mobile devices are expected to roam frequently, compared to wired networks, wireless networking technology is more suitable for mobile networking. For wireless transmission, radio frequency (RF) and optical transmission (like, for example, infrared transmission – IR) may be used. While optical transmission requires a line-of-sight, it offers lower power consumption in general. Thus, Kahn et al. prefer optical transmission for internetworking of *Smart Dust* nodes, which are small computing nodes capable of sensing and networking [3][4].

In many mobile scenarios, a continuous and reliable line-of-sight cannot be assumed. Thus, for example, Mainwaring et al. [41] present an application based on RF *sensor networks* applied to the observation of a physical environment of interest, where parameters like humidity can be sensed. The sensors described (512 kByte non-volatile storage, 916 MHz) are located at areas of interest in the observed field, and are interconnected with one another (at a bit rate of 40 kbit/s) and to a data repository via a gateway.

In sensor networks or other ad-hoc networks, routing is usually not determined by static routes or topologies, but emerges over time. Recently, several routing approaches are under discussion and evaluation. Intanagonwiwat et al. [39] present a *direct diffusion algorithm*, which is capable of empirically deriving the best path, and compare it to *flooding* of messages into the network and an *omniscient multicast* (which refers to IP based sensor networks). Lin et al. [40] compare a *deterministic flooding* approach, which aims at reducing message transfer costs, with *gossip* (also referred to as *rumor mongering*). Rumor mongering uses random selection for communication and is scalable, adaptable in presents of failures, and able to recover. Braginsky et al. [31] propose a rumor routing algorithm based on agent technology. Furthermore, ant based algorithms, like proposed by Subramanian et al. [30], might be beneficial in this area.

For general data communication purposes, a multitude of wireless network technologies are available. While the IEEE 802.11 standard is widely used for indoor Wi-Fi LANs, Bluetooth is mainly used for short distance personal area networks, and Radio Frequency Identification (RFID) is mainly used for short distance supply chain management, like presented by Pentillä et al. [34], for proximity sensing, like presented in Ferscha et. al [33], or for access control purposes. Outdoor connectivity is mainly provided by mobile telephony networks which provide medium bitrates and limited possibilities for (multimedia) data transmissions. In future generations of public cellular networks bitrates ranging from, for example, 144 kbit/s (mobile) and 2 Mbit/s (static) for the recently launched 3G, to 2 Mbit/s (mobile) and 10-600 Mbit/s (static) for 4G, and 100 Mbit/s (mobile) and 600 Mbit/s and more (static) are expected for 5G, as discussed by Ohmori et al. [5].

Thus, applications running on mobile devices will have to be aware of different data transfer rates, of different network providers and, consequently, of different price models and reliability and security support. A goal driven decision support system, which takes these various parameters into account, is needed. Calisti et al. [32], for example, propose negotiations for multi-provider interactions by means of software agents.

Mobile Information Access

In this article, we focus on middleware support in mobile scenarios as a central topic in mobile information access. Here, in addition to traditional coordination issues like discovery services, communication, synchronization, and replication, it has to be considered that components roam in and out of the other participants' transmission range. As a consequence, mobile components will be best supported using concepts of mainly asynchronous communication, reliable and persistent data management and ubiquitous data access.

One possible solution targeting these issues is the use of space based middleware systems, which use the abstraction of a virtual shared data space for coordination and communication purposes, for example, presented by Kühn et al. [15]. This concept of a virtual shared data space originates from the Linda Tuple Space coordination model introduced by Gelernter et al. [16][17] and has fostered many space based approaches and implementations, such as JavaSpaces, which are included in the Jini framework (see Bishop et al. [21]), T-Spaces presented by Lehmann et al. [20], or the distributed CORSO object space, which has been designed, implemented and evaluated under guidance of E. Kühn [15][18][19].

In the research field of intelligent software agents, space technology is widely used. Cabri et al. present the coordination framework MARS [24], which is a tuple space implementation for mobile intelligent agents. MARS adds reflection, that is, the ability of a system to reason about and alter its own behavior, and thus allows the invocation of actions upon events. Another approach targeting coordination of mobile agents is presented in the LIME model by Murphy, Picco et al. [27][28]. Mobile agents merge their interface local tuple space with one another to form a distributed space at a specific agent place. Mobile agents on mobile devices are, for example, supported by the TOTA middleware approach presented by Mamei et al. [25][26]. TOTA focuses on holding context information in the space, on agent-to-space interactions, and on propagation of tuples in a peer-to-peer manner. A typical application scenario is the support of swarm intelligence where each agent implicitly coordinates its actions reflecting the others' behavior.

In order to support operation on shared data, processes on mobile devices will often operate on copies or data previously cached. Creating the copy accurately (that is, for example before disconnecting), efficient synchronization, and data lock management have been identified as key challenges by Imielinsky et al. [29]. The research work of the authors targets these issues and proposes a new approach to assure accurate data processing by means of *mobility awareness*.

The approach merges both wireless link sensing and prediction based reasoning on the link quality of the near future by means of mobility patterns. A *mobility-aware coordination layer* based on space based middleware allows to trigger state change transitions accurately, that is, *before* the process on the mobile device is unable to access shared data caused by link quality degradation or disconnection. Furthermore, this layer provides release of data locks, synchronization, and changes the behavior of coordination primitives depending on the state (for example, in state *connected*, the primitives are used to access and alter the virtual shared object space, in state *disconnected*, the primitives access only local data and keep track of their changes).

Figure 1 shows a prototype implementation on top of CORSO and the Java&Co API. *Network Interface Monitoring* is solved by means of a Wi-Fi client (IEEE 802.11b) and causes – together with the prediction information depending on the used mobility patterns – state changes realized by the *Co-State Machine.* The *Mobility Layer Primitives Module* adapts the behavior of the coordination primitives depending on the state.

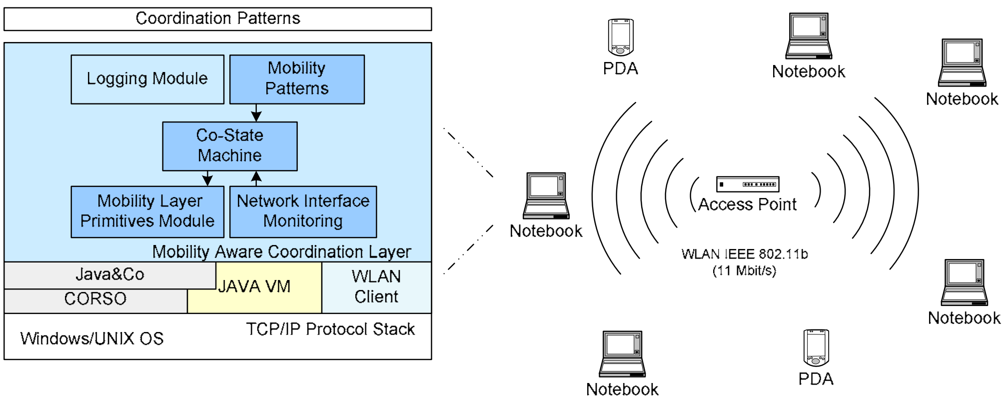

Figure 1. Mobility Aware Coordination Layer Architecture

While working on a copy of the shared data in the virtual shared space, all actions have to be postponed until the process on the mobile device is able to synchronize with the global space. Figure 2 shows a use case of a list data structure, which is visible and accessible via *CREATE*, *WRITE*, *READ*, and *DELETE* operations. While working on a copy of a specific data item (identified by its object identifier, *OID*), actions that cause synchronization with other concurrent processes are not executed, but a flag indicating the action is set (*Activity Flags*).

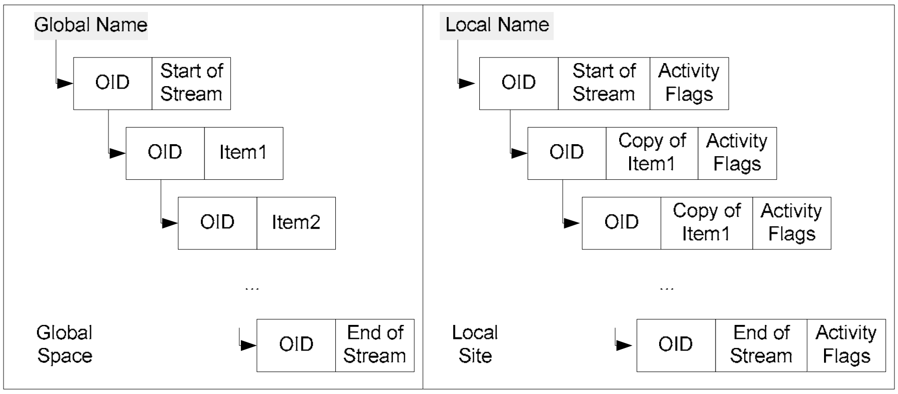

Figure 2. List Data Structure Used for Coordination

The prototype implementation has been applied to a producer/consumer coordination pattern and two heuristically derived mobility patterns: an *order-2 Markov model based pattern* related to the geographical situation of the experimental area and a *smart office pattern,* which assumes information about a person's schedule (for example, taken from calendar entries). First experiments allow an educated guess about the benefits of the approach. The more accurate the mobility model is able to predict the next location or movement, the more advantages can be achieved by pro-active adaptation in terms of availability (as a measure of overall processed data items) and reliability, which refers to failures avoided by means of prediction.

Conclusion and Outlook

The survey presented in this article has focused on three main challenges in mobile wireless networking: mobility modeling, mobile wireless networking while integrating sensors and heterogeneous networks, and mobile information access.

Mobility models can be analytical, derived heuristically or derived by observation and pattern recognition techniques. While analytical models in general simplify human motion, heuristics often depend on special domains or geographical assumptions. In order to derive mobility patterns from an arbitrary set of mobility traces, both statistical analysis and neural networks, like self-organizing maps, as well as new directions from computational linear algebra, have been discussed. A detailed evaluation of these methods applied to mobility traces is currently in progress.

With respect to networking the challenging demands on sensor networks and mobile ad-hoc networks foster adaptive strategies. Agent technology might be used in order to provide emerging robust routing algorithms by means of communication or adapting biological behavior, like in ant based algorithms. Furthermore, agents can be used for negotiation between heterogeneous wireless network providers in a goal driven manner. Here, a detailed definition of goals in terms of quality of service requirements, cost restrictions and security issues, is needed.

The third challenge discussed is related to space based and agent based middleware support for mobility. Here, a mobility aware coordination layer based on the virtual object space CORSO has been described as a selected research work of the authors. By utilizing wireless link quality awareness and mobility patterns for prediction purposes, the layer improves reliability and ongoing access to data in case of disconnections, which can be predicted best when accurate mobility patterns are available.

References

[1] M. Weiser: The Computer for the Twenty-First Century. Scientific American, September 2001, pp. 94-104.

[2] M. Weiser: Some Computer Science Issues in Ubiquitous Computing. Communications of the ACM, vol. 36, no. 7 (July 1993), pp. 75 – 84.

[3] V.S. Hsu, J.M. Kahn, K.S.J. Pister. Wireless Communications for Smart Dust. Electronics Research Laboratory Memorandum Number M98/2, 1998.

[4] J.M. Kahn, R.H. Katz, K.S.J. Pister. Emerging Challenges: Mobile Networking for Smart Dust. Journal of Communication and Networks, vol. 2, no. 3 (September 2000), pp. 188 – 196.

[5] S. Ohmori, Y. Yamao, N. Nakajima. The Future Generations of Mobile Communications Based on Broadband Access Technologies. IEEE Communications Magazine 12 / 2000, pp. 134 – 142.

[6] T. Camp, J. Boleng, V. Davies. A Survey of Mobility Models for Ad Hoc Network Research. Wireless Communication and Mobile Computing (WCMC): Special Issue on Mobile Ad Hoc Networking: Research, Trends and Applications, vol. 2, no. 5, 2002, pp. 483 – 502.

[7] C. Bettstetter, H. Hartenstein, X. Perez-Costa. Stochastic Properties of the Random Waypoint Mobility Model: Epoch Length, Direction Distribution, and Cell Change Rate. In Proceedings of the 5th ACM International Workshop on Modeling Analysis and Simulation of Wireless and Mobile Systems, 2002, pp. 7 – 14.

[8] L. Song, D. Kotz, R. Jain, X. He. Evaluating Next-cell Predictors with Extensive Wi-Fi Mobility Data. Dartmouth College Computer Science Technical Report TR2004-491, February 26, 2004.

[9] ETSI. Selection Procedures for the Choice of Radio Transmission Technologies of the UMTS (UMTS 30.03 version 3.2.0). European Telecommunications Standards Institute Technical Report TR 101 112, April 1998.

[10] T. Ziegert. Lokalisierung mobiler Teilnehmer unter Berücksichtigung regelmässigen Verhaltens. In Proceedings of KiVS, February 2001, pp. 265 – 278.

[11] J.G. Markoulidakis, G.L. Lyberopoulos, D.F. Tsirkas, E. D. Sykas. Mobility Modeling in Third-Generation Mobile Telecommunication Systems. IEEE Personal Communications, August 1997. pp. 41 – 56.

[12] A. Jardosh, E.M. Beiding-Royer, K.C. Almeroth, S. Suri. Towards Realistic Mobility Models for Mobile Ad hoc Networks. In Proceedings of 9th Annual International Conference on Mobile Computing and Networking, 2003, pp. 217 – 229.

[13] M. Satyanarayanan. Pervasive Computing: Vision and Challenges. IEEE Personal Communications, vol. 8, no. 4 (August 2001), pp. 10 – 17.

[14] J. Ziv, A. Lempel. Compression of Individual Sequences via Variable-rate Coding. IEEE Transactions on Information Theory, vol. 24, no. 5 (September 1978), pp. 530 – 536.

[15] E. Kühn, G. Nozicka. Post-Client/Server Coordination Tools. Coordination Technology for Collaborative Applications, vol. 8, 1998.

[16] D. Gelernter. Generative Communication in Linda. ACM Transactions on Programming Languages and Systems, TOPLAS, vol. 7, no. 1 (1985), pp. 80 – 112.

[17] D. Gelernter, N. Carriero. Coordination Languages and their Significance. Communications of the ACM, vol. 35, no. 2 (1992), pp. 97 – 107.

[18] E. Kühn. Introduction: How to Approach the Virtual Shared Memory Paradigm. Journal of Parallel and Distributed Computing Practises, Special Issue on Virtual Shared Memory for Distributed Architectures, vol. 1, no. 3 (1998).

[19] E. Kühn. Coordinated Shard Object Spaces V1.2. White Paper, 2002, TECCO Software Entwicklung, Prinz Eugen Strasse 58, A – 1040 Wien.

[20] T.J. Lehmann, S.W: McLaughry, P. Wycko. T Spaces: The Next Wave. In Proceedings of the 32nd Annual HICCS, vol. 8 (1999), pp. 8037 –

[21] P. Bishop, N. Warren. JavaSpaces in Practice. Addison-Wesley. 2003.

[22] A. Rauber, D. Merkl. Text Mining in the SOMLib Digital Library System: The Representation of Topics and Genres. Applied Intelligence, vol. 18, no. 3 (May/June 2003), pp. 271 – 293.

[23] A. Rauber, D. Merkl, M. Dittenbach. The Growing Hierarchical Self-Organizing Map. Exploratory Analysis of High-Dimensional Data. IEEE Transactions on Neural Networks, vol. 13, no. 6 (November 2002), pp. 1331 – 1341.

[24] G Cabri, L. Leonardi, F. Zambonelli. MARS: A Programmable Coordination Architecture for Mobile Agents. IEEE Internet Computing, vol. 4, no. 4 (2000), pp. 26 – 35.

[25] M. Mamei, L. Leonardi, M. Mahan, F. Zambonelli. Coordinating Mobility in a Ubiquitous Computing Scenario with Co-Fields. In Proceedings of the Workshop on Ubiquitous Agents on Embedded, Wearable, and Mobile Devices (AAMAS 2002).

[26] M. Mamei, F. Zambonelli, L. Leonardi. Programming Coordinated Motion Patterns with the TOTA Middleware. In Proceedings of Euro-Par 2003, pp. 1027 – 1037.

[27] A.L. Murphy, G.P. Picco, G.-C. Roman. LIME: A Middleware for Physical and Logical Mobility. In Proceedings of the 21st International Conference on Distributed Computing Systems (2001), pp. 0524 –

[28] G.P. Picco, A.L. Murphy. G.-C. Roman. Developing Mobile Computing Applications with LIME. In Proceedings of International Conference on Software Engineering (2000), pp. 766 – 769.

[29] T. Imielinski, B.R. Badrinath. Mobile Wireless Computing: Challenges in Data Management. Communications of the ACM, vol. 37, no. 10 (1994), pp. 18 – 28.

[30] D. Subramanian, P. Druschel, J. Chen. Ants and Reinforcement Learning: A Case Study in Routing in Dynamic Data Networks. In Proceeding of IJCAI, 1997, pp. 832 – 839.

[31] D. Braginsky, D. Estrin. Rumor Routing Algorithms for Sensor Networks. In Proceedings of the 1st International Workshop on Sensor Networks and Applications (2002), pp. 22 – 31.

[32] M. Calisti, B. Faltings. Agent-Based Negotiations for Multi-Provider Interactions. In Proceedings of the 2nd International Symposium on Agent Systems and Applications / 4th International Symposium on Mobile Agents, September 2000, pp. 235 – 248.

[33] A. Ferscha, W. Beer, W. Narzt. Location Awareness in Community Wireless LANs. In Proceedings Informatik 2001, September 2001, pp. 190 – 195.

[34] K. Penttilä, P. Salonen, M. Keskilammi, M. Kivikoski, L. Sydänheimo. Visibility of a Supply Chain with Passive RFID Technology and Product Codes. In Proceedings of the SSGRR03w, January 2003.

[35] M.W. Berry (Ed.). Computational Information Retrieval. Proceedings of CIR'00, SIAM Proceedings in Applied Mathematics, 2001.

[36] M.W. Berry, M. Browne. Understanding Search Engines: Mathematical Modeling and Text Retrieval. SIAM Book Series: Software, Environments, and Tools. June 1999.

[37] D. Ashbrook, T. Starner. Using GPS to Learn Significant Locations and Predict Movement Across Multiple Users. Personal and Ubiquitous Computing, vol. 7, no. 5 (2003), pp. 275 – 286.

[38] J. Chan, S. Zhou, A. Seneviratne. A QoS Adaptive Mobility Prediction Scheme for Wireless Networks. In Proceedings of IEEE Globecom, November 1998.

[39] C. Intanagonwiwat, R. Govindan, D. Estrin. Direct Diffusion: A Scalable and Robust Communication Paradigm for Sensor Networks. In Proceedings of the 6th International Conference on Mobilie Computing and Networks, August 2000, pp. 56 – 67.

[40] M.J. Lin, E. Marzullo, S. Masini. Gossip versus Deterministic Flooding: Low Message Overhead and High Reliability for Broadcasting on Small Networks. In Proceedings of the 14th International Conference on Distributed Computing, October 2000, pp. 253 – 267.

[41] A. Mainwaring, D. Culler, J. Polastre, R. Szewczyk, J. Anderson. Wireless Sensor Networks for Habitat Monitoring. In Proceedings of 1st ACM International Workshop on Wireless Sensor Networks and Applications, 2002, pp. 88 – 97.