# Using Ambient Intelligence to Infer Availability and Meta-status in a Picocell Environment

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***Abstract*—Pervasive mobile communication is set to be greatly enhanced by the development and deployment of miniature mobile base stations, suitable for workplace or home. These base stations, known as Femtocells and Picocells, connect to traditional broadband connections, to offer greatly improved 3G communications to mobile handsets. Developing an architecture that allows for targeted applications to be developed for end users of these enhanced mobile networks is of great importance. Examining how contextual data, extracted from these mobile networks, can be used to make inference and provide benefit to end users is both a technical and sophisticated challenge to be discussed in this paper.**

***Index Terms*—Ambient Intelligence, Femtocell, Inference, Picocell**

## I. INTRODUCTION

FEMTOCELLS and Picocells are delivering an innovative infrastructure to localized network environments such as workplaces, conference centers, and even homes. Allowing data connections of broadband capacity on cellular devices, these compact base stations are already making a major impact on how we use mobile data services. Femtocells and Picocells allow for the simple creation of micro-cellular [1] environments with limited range, effective between 5,000 and 30,000 square feet, respectively. Femto Access Points (FAP's) are lower power, small base stations which resemble a WiFi router and also known as Home NodeB's. These micro-cellular environments augment macro-cellular coverage provided by a network operator by enabling homes and businesses to reuse their existing broadband connections (e.g. xDSL, cable) to make phone calls and access data services using their standard GSM handsets. The advantages of the technology include: improved coverage, reduced infrastructure and reduced power consumption by the handset. [2]

While the opportunity for network operators to offload data transmissions from their macro-cellular network is a clear benefit, femto-cell technology is not without its problems. Principally, the optimisation of frequency usage between the femto microcellular network and the operator's established macrocellular network. [3].

Responding to these challenges, standardisation groups such as the 3GPP have designed architectures [4] that integrate the network management (e.g. spectrum allocation, power and QoS) functions of macro and femto cellular networks. This means that these micro-cellular environments can be harvested for user data such as accounting type usage data and also contextual usage data that can be used to drive any number of personalized and/or premium services to users of the femto/pico cell network.

The challenge of developing a lightweight, yet robust, platform architecture that fuses seamlessly with the core network of the miniature base stations is a largely unexplored domain. The integration of event management, context data correlation, and accounting/billing is key to the future development of this area and for the future of applications specifically targeted at micro-cellular environments. As operators expect that consumers will purchase their own micro-cellular infrastructure, albeit subsidised, incentives such as reduced call costs or new value-added services are deemed important to drive femto rollout. [3]

Derived from work done on the GenesisX[1] project, this paper describes a platform for maximizing the application of contextual data from micro-cellular environments such as Femtocell/Picocell networks.

## II. GENESISX PLATFORM ARCHITECTURE

The goals of the GenesisX platform are:

- Support the rapid development of applications and services that work seamlessly over both micro and macro-cellular networks.
- Provide web service interfaces to access context information from micro-cellular networks
- Create demonstrator applications which show the platform benefits.

These goals have been achieved by creating a micro-cellular Pico Service Platform (section II), augmenting existing work in SOA-IMS (IMS development using SOA principles), design and implementation of a suitable test platform (section III) and the development of a demonstrator service (section IV).

The platform architecture for GenesisX has been designed with decoupling and layering in mind so as to allow for additional features to be deployed with minimal disruption to any existing services. As such, we have followed a Service Orientated Architecture (SOA) using an Enterprise Service

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Bus (ESB) as the middleware to facilitate the publishing of component interfaces as web services rather than more technical protocols e.g. SIP or Diameter. An outline of this architecture is shown in Figure 1.

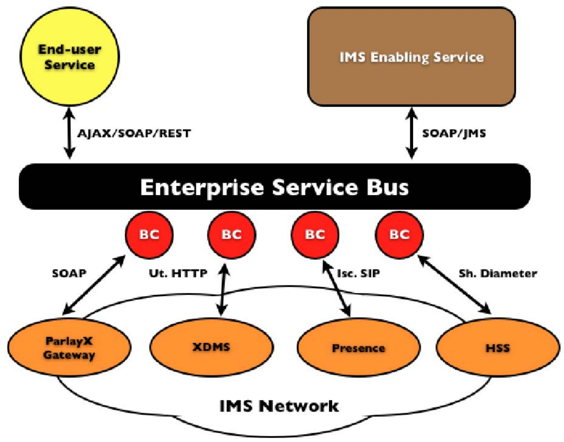


Figure 1. ESB Interface with IMS Network

- The End-User service represents the service business logic. It accesses network features via web service protocols, e.g. Ajax, SOAP. The End User Service may be implemented in a range of languages, from compiled languages such as Java to interpreted languages such as Javascript.
- The IP Multimedia Subsystem (IMS) is an architecture for IP telecommunications network originally defined by the 3GPP [5]. It uses IETF defined protocols such as SIP[6] and Diameter[7]. Global IMS standardisation efforts for mobile and fixed access networks are unified under the ETSI Next Generation Network (NGN) banner.[8]
- The Enterprise Service Bus mediates between the Web Service Interfaces expected by the End User Services and the IMS telecommunications protocols offered by the IMS Network. e.g. the Session Initiation Protocol (SIP) and various Diameter interfaces for querying subscriber data, billing data, etc. This mediation occur using reusable protocol adapters known as Binding Components (BC's).
- The IMS Enabling Service is a bundle of reusable functionality that may be composed by multiple End user services. Examples of Enabling Services include a Conferencing Service to setup voice/video conferences or a Context Engine to analyse subscribers context information.

The GenesisX platform uses a standards-compliant ESB to connect to the existing Genesis application Server. This is then augmented with binding components, which facilitate communication with NGN nodes such as the Home Subscriber Server (HSS), Call Session Control Functions (CSCFs), Charging Gateways etc.

ServiceMix is an implementation of the JSR 208 also known as the Java Business Integration (JBI) specification. The goal of JBI is to allow components and services to be integrated in a vendor-independent way. It provides a common way to route messages between end-points with protocol adaptation mechanisms where required. In JBI a Normalized Message Router (NMR) mediates messages between components. The NMR serves as an intermediary for routing messages amongst plug-ins, no matter where that component resides. Plug-ins dont communicate directly with one another; they only communicate with the NMR. This provides location transparency for the plug-ins. Figure 2 illustrates the ServiceMix architecture [9].

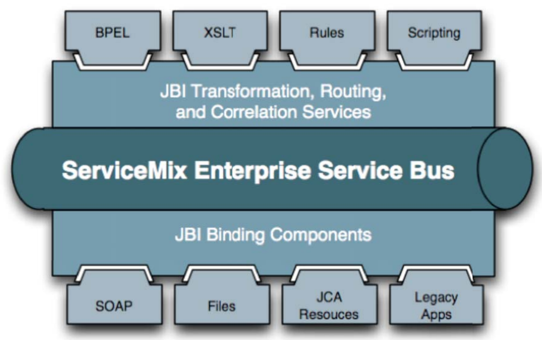


Figure 2. ServiceMix Enterprise Service Bus

There are several advantages to using an Enterprise Service Bus in creating applications combining ambient intelligence and telecommunications services. The service bus can mediate between sensor data types. Data and Telecommunications API's can be given an homogenous web service interface and are hence easier to adapt and compose by the large web development community familiar with technological approaches such as AJAX and REST.

The enterprise service bus is capable of running in a decentralized manner and providing template implementations of well known Integration Patterns for message routing that are directly applicable to telecommunications applications. Examples include pipes, filters (e.g. for logging), Content based routers (routing based on message type e.g. XPIDF presence data[10]), Recipient List (for delivery of messages to many parties). As part of this work, the authors have further developed a suite of IMS protocol Binding Components they developed on earlier projects. [11]

## III. Testbed Facilities

The research has been carried out using a 2.5G Pico Cell-to-IMS adapter provided by Irish company Druid Software [12]. The authors have enhanced the adapter with a RESTful interface to enable information to be extracted about the Cell-Id and signal strength of each subscriber's mobile phone. The adapter connects 2, 2.5G Pico base stations to an Ericsson IMS testbed, located at the NGN Test Centre [13]. The testbed was designed to reflect the architecture for *"medium and large-scale"* deployments of microcellular technology described in [2]. As our intended usage scenario anticipates wide-spread adoption of micro-cellular technology and, therefore, many femto/pico cells gathering contextual data, our testbed uses the Druid adapter as a Femto-GateWay (FGW) which can aggregate the connections of many BTS's and coordinate the collection of context information.

Our Pico base transceiver station (BTS) adheres to the GSM 0.5.10 Pico specifications and operating in the GSM 1800 band (1805-1880MHz) at low power (+23dBm). They support an A-bis over IP interface for signaling and management between the BTS and the adapter, which then bridges to the IMS core. Thus signaling and bearer voice channels are presented to the IMS network and can be used by IMS applications. Calls, SMS and data services over Enhanced General Packet Radio Service (E-GPRS or EDGE) are provided. An explanation and history of EDGE technology is provided at [14]. Our micro-cellular testbed will be enhanced to support 3G but the EDGE system's 296 Kbps limit was not an issue for our trials.

The NGN test centre is an Irish nationally funded initiative to provide a carrier-grade NGN test infrastructure to indigenous technology companies. The platform is also used on European research projects. It consists of an Ericsson-provided IP Multimedia Subsystem (IMS) Core incorporating subscriber database and switching functions. A full Operations and Maintenance (OAM) system is provided with fault-diagnostic capability. Breakout to the Public Telephony Network (PSTN) is enabled via a Media Gateway (MGW) while access to and from the network is controlled using IMS Access and Network Session Border Controllers (A-SBC & N-SBC).

## IV. Demonstrator Service

Customer relationship management (CRM) is a broadly recognized, widely implemented strategy for managing and nurturing a companys interactions with customers, clients and sales prospects. It involves using technology to organize, automate, and synchronize business processesprincipally sales activities, but also those for marketing, customer service, and technical support. As part of this work, the authors have implemented a CRM system from scratch. Goals for the implementation included a clear structure and easy-extensibility using Ruby. A set of features specific to GenesisX has been added. CRM integration with Femto/Pico cells provides the basis for a set of scenarios that can be further developed on GenesisX, demonstrating a real-world usage of a Pico Service Platform. Specifically a Pico Service Platform should be able to provide the following facilities:

- Coarse-grained location information for subscribers depending on which Femtocell/Picocell they are connected to.
- Presence information. Extended presence formats such as XPIDF may be used as a way of making location information available to 3rd parties, where permissible.
- A web service interface to enable easy integration with 3rd party software.
- A facility to send SMS and MMS messages to other users of the CRM system.
- Presence-based dialer features such as click-to-dial.

TSSGs implementation of a Pico-enhanced CRM system is called XRM or eXtensible Relationship Manager. The XRM platform is web-based. Apart from an Internet browser, no specific hardware or client application software is required. However, an iPhone application has been developed which integrates the application with the phone's native API's for short and multimedia-messaging and location.

The XRM uses use common functionality from the GenesisX Pico Service Platform. This includes transformation of SIP messages to/from Web Service requests, context-based call routing and context aggregation e.g. combining presence and location information into the rich presence XPIDF format.

These web service building blocks are used within the Ruby implementation of XRM. Ruby was chosen, as it is a highly productive and much-used web application language, benefitting from the Rails framework, which simplifies web development.

## V. Context Information

The inclusion of presence information in IMS is one of the key differentiators between IMS and legacy IN systems. Presence is a rich source of context information, potentially for users, devices and services.

The Femto/pico presence agent (see Figure 3) is an Enabling Service hosted within an IMS application server that enables presence information to be extracted from devices that dont provide direct software support for the SIP-based publish-subscribe presence mechanism of IMS. An example of such a device is 2G/3G mobile terminal featured in the previous scenarios.

The presence agent uses our SOA based approach, leveraging TSSGs IMS Binding Components to provide presence information about subscribers accessing the IMS core through the Pico-to-IMS adapter.

To make use of the available presence information, a number of developments were carried out to create building blocks capable of producing the elements of a service for SMEs.

The creation of presence agents, integrated within a Pico/Femto infrastructure means that GSM mobiles become a source of presence information including location, general availability and sub-status (e.g. on-the-phone). Femto infrastructure is cheap, leveraging commodity chipsets, meaning that this technology is suitable for deployment by SMEs.

The ability to infer or enhance presence sub-status based on Bayesian Belief Networks. For example, John has accepted a meeting at 10:00h in room G.2 on the ground floor of his office block. The picocell indicates that John is on the ground floor and the time is 9:55 therefore his sub-status can be inferred to be attending a meeting.

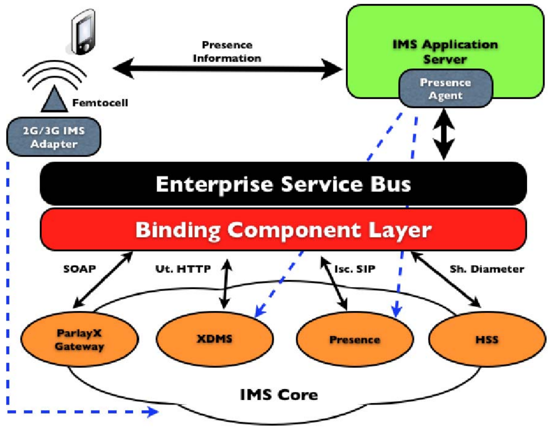


Figure 3. Femto/Pico Presence Agent

The context information provided by the Pico Service Platform in the form of presence updates may be charged for on a per-update basis or simply monitored and audited to verity that a number of presence changes have been recorded for an individual subscriber or group of subscribers. Mechanisms for "micro-charging" for content and information over IMS networks have been proposed by the authors.[15] as has the generation of charging schemes for composed IMS services [16], this being relevant in situations where there are multiple providers of context information or context inference. A business could buy a package of relevant (filtered) context-updates for a group of subscribers who are employees of the business, which can then be used to update the businesses information systems. In the case of the GenesisX project, the updated system is the XRM, described earlier.

## VI. Inferred Attendance Scenario

Inferring information from a set of known context data is a very beneficial process. It saves time and increases productivity from the perspective of the subject under analysis; it yields interesting and valuable results from the point of view of systems that can exploit the contextual existence of a person or thing. To explore this further we investigated a test scenario of meeting attendance.

The infrastructure available for this test scenario comprises 3 Picocells, positioned at key points in an office block. The inference engine used to make assumptions about the users presence has a resolution of 20 seconds, whereby it polls for information from the various components such as shared calendars for appointment details and base transceiver stations (BTS) for signal strength and current connection status. The calendar manager pushes event data to the system, for upcoming events. Polling the calendar thereafter serves the purpose of identifying last minute changes or cancellations that may occur after the initial event reminder, thus reducing the likelihood of false positives generated by the inference engine.

The purpose of this system is not to accurately locate an individual but rather to infer the likelihood that they are engaging in a specific activity such as a pre-arranged meeting. Thus, a combination of signal strength changes between polling intervals can infer motion; handover between one BTS and another can infer direction. If the resultant vector is towards a meeting room where a scheduled event is to take place then it can be inferred that the person is making their way to the room.

John works in a shared office block, with meeting rooms dispersed throughout the building. Johns working schedule is managed through XRM. XRM allows John to schedule meetings with contacts, follow up on leads, and maintain a shared calendar so that colleagues are aware of his availability. Johns workplace network infrastructure offers a micro-cellular environment using pico and femto cells managed by Druid's FGW, which is in turn connected to the IMS core of the company's preferred network operator.

On Monday morning John schedules a meeting with a customer, in one of the ground floor meeting rooms, for 10:00h. John has also invited his colleague Mary, to attend the meeting. These details are entered into the XRM through Johns account. At 09:55h Mary meets the customer at reception and guides them to the meeting room on the ground floor. Once inside, Mary changes her status to reflect that she is unavailable due to being in a meeting. The scheduling service receives Marys status change and cross-references the details with the XRM. Through both the presence information set by Mary and the location information acquired through the Pico infrastructure, the system knows that Mary is now attending the meeting scheduled by John. It also knows that John is not yet at the meeting because his location is currently at the first floor. A pop-up reminder informs John that the meeting is now underway and that he should hurry to the room. John makes his way to the stairs and towards the ground floor meeting room. The system is aware of Johns location change and is able to correlate this with the prior events of Mary entering the meeting room, Mary setting her status to unavailable, and the scheduled event in the XRM. By applying a Bayesian probability calculation to the various pieces of contextual information, the system can infer that John is now on his way to the meeting and thus set his sub-status to arriving at a meeting and his status to unavailable. This saves John the trouble of manually changing his status and also makes his meeting with the customer more professional as he does not have to interact with his mobile device upon starting their meeting.

Finally, once on the ground floor, Johns mobile device undergoes a handover between the first floor BTS and the ground floor BTS. The inference engine now knows that John is in the vicinity of the meeting room and thus updates his sub-status to attending a meeting and preserves his status as unavailable.

Figure 4 shows the route taken by John from his first floor location to the meeting room on the ground floor. There are two BTS handover points as John moves closer to each cell in the building. The directional blue lines represent the inferred vectors of Johns movement. The red dots represent the actual

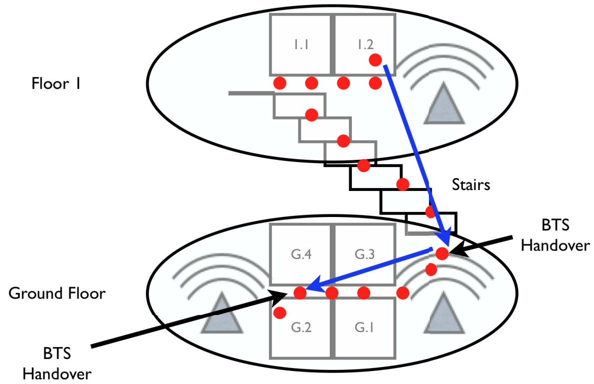


Figure 4. BTS Handover and Inferred Movement

path taken. It can be seen at each of the handover points that a vector is drawn, indicating the general path of movement towards the G.2 meeting room. These vectors provide realistic directional information despite the positioning of the stairs that forms an indirect route to the room.

Although John is navigating through 3-dimensional space, via an indirect route to the meeting room, the ultimate trigger for John's status change is the handover to the BTS closest to the meeting room. His journey is effectively the sum of the vectors created by the different BTS handovers on his route. The two vectors shown in Figure 4 as blue lines, effectively give way to a third unseen vector that connects the origin of John's journey to the destination meeting room. If $\vec{v}_1$ and $\vec{v}_2$ represent the blue line vectors then this vector, $\vec{v}_3$, is defined by:

$$\vec{v}_1 + \vec{v}_2 = \vec{v}_3, \text{ where}$$
$$\vec{v}_1 = (x_1, y_1, z_1),$$
$$\vec{v}_2 = (x_2, y_2, z_2), and$$
$$\vec{v}_3 = ((x_1 + x_2), (y_1 + y_2), (z_1 + z_2))$$

The coordinates are contained within a Cartesian plane — this system of coordinates is best suited to the scenario as the office floorspace is typical of a cubic domain. The domain of the BTS signals and range may be better described within a system of polar coordinates, where spherical symmetry would typify the radio wave outputted. However, it is the position of the individual within the building and not within the waveform that is being analysed. Thus, vector coordinates leading to the catchment area of the meeting room, confirm the path travelled with a degree of certainty.

Behind the scenes, this seamless process is made possible by the interaction of presence agents, location agents, the XRM system, and a Bayesian reasoning Service Enabler to calculate the probability that events are related to each other.

## VII. Inference and Learning

The inferred data in the scenario above can be described as automatic tracking of an individual. However, the purpose of this tracking is not to determine the exact location of a person. Triangulation and handset positioning in small-scale wireless networks has been extensively covered by other research and is not the focus of this paper.

The type of data inferred in the presented scenario is generic in nature and is respectful of peoples privacy. Motion can be derived by analyzing changes in signal strength between the mobile device and the BTS. The weaker the signal strength, the further away the mobile device is from the heart of the BTS and vice versa. This coarse-grained and location inaccurate information is sufficient to infer that somebody is on the move this is all that is required of the service.

When a mobile device engages in handover between BTS nodes it is then possible to infer the direction of motion. Certain tolerances for signal strength are configured such that a device will always connect to the BTS with which it has the best signal. Thus a progressively weakening signal strength coupled with an eventual BTS handover allows for a general path of motion to be plotted. This in turn, as per the scenario above, can be used to indicate a persons route to a specific room.

The value of the service is to dynamically and automatically update the persons status, to indicate whether or not they are attending a meeting. As a result of this inference there are three possible outcomes:

(i) The status is updated to attending a meeting the end-user can see at a glance that this has happened, is an accurate reflection of their status and take no action.
(ii) The status is updated to attending a meeting the end-user notices the status change, identifies it as being an inaccurate reflection of their status and takes corrective action.
(iii) The end-user gets to the meeting but the system has not yet changed the status. The end-user manually updates the status to reflect their unavailable state.

Outcome (i) would be an example of a perfectly functioning system. Outcome (ii) would be an example of a false positive whereby the system has predicted meeting attendance but for whatever reasons this is no longer a correct assumption. Perhaps failure to update the schedule or last minute meeting cancellation is responsible for this outcome. Outcome (iii) would be an example whereby one of two things has occurred. Either the update frequency of the system has not had a chance to update the users status or the system believes that the user is not within the vicinity of the schedule meeting room. Any false positives or status updates requiring manual intervention are fed back into the system for further analysis. If the system is at fault then it needs to update its probability weightings for the given sequence of events. If user error is the source of the problem e.g. meeting cancelled but not updated in XRM, then the system can disregard the false positive, as the problem lies external to the system.

Bayesian networks (BN) have evolved as a major tool in a wide area of scientific disciplines requiring sound statistical analysis, automated reasoning or exploitation of knowledge hidden in noisy data. A BN is a probabilistic model consisting of a Triplet $(V, E, P)$, with a set of Random Variables (RVs) $V = A_1, A_2, ..., A_n$, a set of dependencies $E = \{(A_i, A_j) | i \neq j, A_i, A_j \in V\}$ without directed cycles between these RVs and a joint probability distribution (JPD)

$$P(V) = P(A_1 \cap A_2 \cap \ldots \cap A_n) = \prod_{i=1}^{n} P(A_i | pa(A_i))$$

where

$$pa(A_j) = \{A_i | \forall A_i \in V \wedge (A_i, A_j) \in E\}$$

are the parents of $A_j$.

In our system, the random variables V represent the probability that a Person $(r)$ is attending a meeting $(m)$ at location $(l)$ and time $(t)$. The JPD therefore considers the associated conditional probabilities, given dependencies $E$, including the probability that: $r$ is moving towards the meeting room's location $l$ OR has already arrived there; a meeting in location $l$ is likely to occur (the room/office may be unavailable); the meeting $m$ is already taking place given other attendees are present OR have already confirmed, using the described presence mechanism, before the start time.

The message sequence chart shown in Figure 5 shows that a Markov Chain [17] is used as part of the inference process. Markov Chains are a suitable, mathematical model for representing the behaviour of a non-deterministic finite state machine [18]. Markov Chains work on the principle of a state matrix and a transition matrix, whereby probabilities of moving from one state to another can be applied to determine the most likely outcome of the system. Continual sampling of statistical data pertaining to the system can also feed back into the matrix of probabilities, allowing the system to maintain accuracy over time. Markov Chains and Hidden Markov Models (HMM) are a proven way of factoring systems where unobservable states have recognizable outcomes [19].

It is the value added by removing onerous tasks from peoples daily working lives that is of significant interest. It has been shown by [20] that both productivity and work satisfaction increase through attentive and reactive environments such as this scenario presents. Removing trivial tasks from a persons working life makes them feel as though more is being achieved with their time and greater job satisfaction results from this.

The overall workflow and message sequencing for the scenario is illustrated in Figure 5.

## VIII. Conclusion and Discussion of Ongoing Work

Working with inferences in a Picocell environment presents interesting challenges and valuable outputs. Acknowledging the inappropriateness of precise location information, normally acquired through sophisticated triangulation techniques, and allowing additional context information to compensate for location inaccuracy, still makes it possible to infer the exact location and status of an individual within a working environment. Once seeded with suitable, initial probabilities of certain outcomes resulting from known events the system can be trained with minimal, manual intervention.

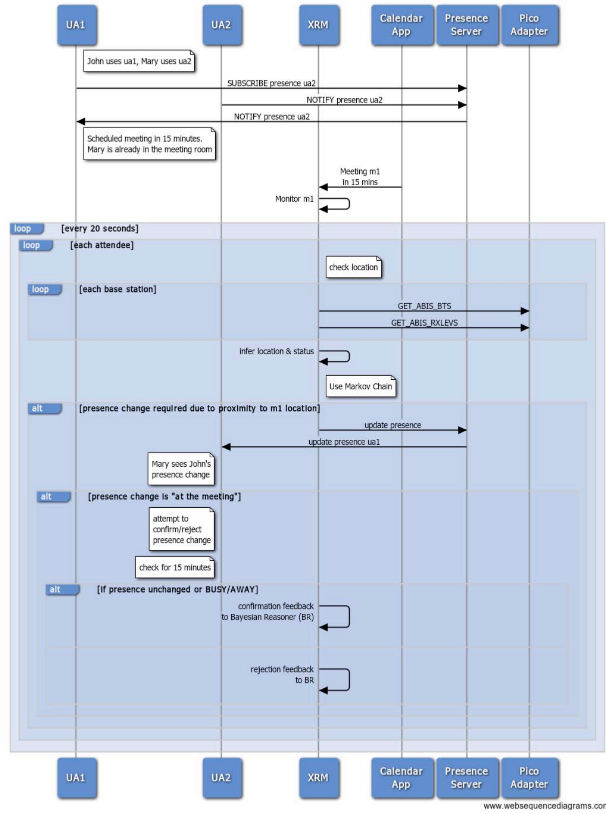


Figure 5. Presence Inference Message Workflow

Our demonstration system was simplified due to the coarse-grained nature of the data being acquired. Sophisticated tracking algorithms were not required to deduce location in a 3-dimensional space. However, we have designed our system for extensibility and we're currently experimenting with more sophisticated "Bayeslet" approaches to context inference, based on our colleagues work [21]. Bayslets enable a complex bayesian network to be subdivided into smaller RV groups (see VII). For example, motion and presence activity may be treated as separate Bayesian Networks, implemented using different JBI "java beans" and mathematically combined using the rules described in [22]. This is an inherently more scalable approach than the one we have taken as context inference is more easily expressed as smaller networks that are "fused" based on well defined and rules.

It is notable that our system provides cheap context. The cost of Femtocell nodes is very affordable ($\leq$ \$100) and additional operational data can be coupled from the companys existing CRM solution (e.g. SugarCRM [23]) and instant messaging network (e.g. Jabber [24]).

## Acknowledgment

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and which have contributed directly to the formation of this paper.

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