Analysis, Decision Making and Security Issues in Mobile Information Systems

Niall O'Donoghue, Seppo Puuronen and Vesa Savolainen

University of Jyväskylä
Department of Computer Science and Information Systems
P.O. Box 35
FIN-40351 Jyväskylä
FINLAND
e-mail vesa.savolainen@jyu.fi

Abstract: In the area of mobile computing, extensive research has been made for defining and constructing the concepts and forms of *Mobile Information Systems* to support the everyday tasks of executives and experts when they are travelling. The main functional areas of Mobile Information Systems are information, communication, analysis and decision making, and office work support - all overlaying a mobile environment. This paper focuses on analysis and decision making tools, security and anonymity issues and on communication architecture in Mobile Information Systems. We will suggest methods for combining data views to perform analysis, for coordinating decision making, as well as for problem solving and group decision making. The security and anonymity of the *Executives' Mobile Personal Information System* (EMPIS) are studied from the viewpoints of the concept of an EMPIS travelling alias, GSM limitations, time-based aliasing, and shared key encryption. The EMPIS communication architecture is analysed from such viewpoints as routing challenges in an ad hoc mobile environment, the relevance of bandwidth to EMPIS communication, and data transfer by asynchronous transfer mode.

Keywords: mobile information system, executive information system, mobile computing, analysis, decision making, office work

Mr. Niall O'Donoghue started his studies at University College Cork (U.C.C.), Ireland in 1985. He graduated with an honors B.A. degree in 1988. This was followed by a postgraduate diploma in Education (1988-89) and another postgraduate diploma in Computer Science (1989-90). Immediately on graduating, he began his career as a software tester at Lotus Corporation's European software localization facility in Dublin. He later took a similar position at Microsoft Corporation's European localization facility, also in Dublin, and adopted a variety of roles including project team leadership. In 1994, he decided to study further for an MSc. at the Department of Computer Science and Information Systems at Jyväskylä University in Finland. He has since carried out successful research in the area of executive mobile computing (MEMPHIS Project). He will carry out further research in this area for his Ph.D thesis. He has also become involved in Internet website and multimedia production, which will benefit his mobile computing research. Currently he is working for NOKIA Mobile Phone, Ltd.

Dr. Seppo Puuronen is acting as a Professor in Information System Science at the University of Jyväskylä. He received his Ph.D (economics) in Computer Science in 1988 at the University of Jyväskylä. In 1983-88 he worked at Lappeenranta University of Technology as associate professor and senior lecturer of computer science and during 1989-97 as acting associate professor and full professor at the University of Jyväskylä. He has acted as a member of the Program Committee of the Finnish Artificial Intelligence Symposium in 1988 and as a tutorial chair of CAISE'95. He has acted as Head of the Department of Computer Science and Information Systems at University of Jyväskylä in 1988-89, 1990-91 and 1997. He has authored several international journal and conference papers. His main research interests are knowledge-based systems, semantic nets, expert systems and knowledge engineering, computers in education, and mobile computing.

Dr. Vesa Savolainen is Professor of Computer Science (information systems). He received his MSc. in 1971, Ph.Lic in 1973 and Ph.D in 1977 in Computer Science at the University of Tampere. He became associate professor in 1980 at the Vaasa School of Economics. He worked as a professor of applied mathematics in 1982 and a professor of computer science over 11 years in the period 1981-97 at the University of Jyväskylä. He was Head of the Department of Computer Science and Information Systems at University of Jyväskylä in 1981, 1993-94 and 1996. He participated in the ESPRIT Project OSSAD, Office Support Systems Analysis and Design, in 1986-89, and ESPRIT Project HECTOR, Harmonized European Concepts and Tools for Organizational Information Systems, in 1989-90. He is a senior member of IEEE and a member of ACM and IFIP WG 8.4 (Office Systems) and WG 8.3 (Decision Support Systems). He has authored quite a number of scientific international, refereed papers on information systems, and also 3 books: *Information Resource Management in Organizations, Foundations and Algorithms of Graph Theory and Perspectives on Information System Development*. His main research interests are mobile information systems, multimedia information systems, information system development methodologies, methods and tools, dynamic modelling of information systems, graph theory and applications, performance evaluation of information systems, measurement information systems and executive information systems.

1. Introduction

The EMPIS (Executives' Mobile Personal Information System) Project [27, 31] was launched in 1995 as a cooperation between the University of Jyväskylä and NOKIA Research Centre in Finland. The aim was to analyse European executives' practices and requirements in mobile information system services. We interviewed 49 executives who travel nearly 20% of their time and utilize several types of IT services. Two central areas of these services are information and communication services which were analysed in [27]. Two other central IT support areas, which became well known in wired Executive Information Systems, are decision making, analysis and office work support (see [8, 27, 28, 34 and 42]). Our project defined the EMPIS to be a Mobile Information System that offers executives all the necessary information system services when they are travelling [27, 31, 32].

The case studies among 49 executives [31] revealed that 32% of them expected, with some positive probability, to introduce a *mobile decision support system* within two or three years. Correspondingly, 41% wanted to introduce a *mobile executive information system* and 31% *computerized project monitoring support*. They wanted these services via a portable pc and mobile phone - if they were available at a reasonable price. Other corresponding percentages of interest concerning mobile IT services were:

- 52% for *text processing*,
- 75% for *electronic mail,*
- 56% for *information access to own company's databases,*
- 46% for *World Wide Web,*
- 40% for *task oriented reports,*
- 37% for *tracking of critical success factors,*
- 27% for *making what-if question analysis,*
- 37% for *exception reporting,*
- 48% for *multimedia information systems*,
- 58% for *group work support*, and
- 42% for *video meeting support.*

All of these IT services, except for multimedia information systems [7, 16, 19, 24, 33], group work support [3, 5, 10, 12] and video meeting support, are today, to some extent, technically available to travelling executives via laptop and mobile phone connections to the corporate computers (see Satyanarayanan [35]).

Increased computer literacy among executives and upper management has led to increased usage of decision support and data analysis applications. The most common of these applications is probably the spreadsheet. Spreadsheet functions, for example in Microsoft Excel, have been found to be useful for planning and control purposes, and according to Partanen and Savolainen [28] and Rockart and De Long [34] useful for improving mental models and for supporting miscellaneous data analysis which is carried out occasionally by executives. Therefore we propose that it can be beneficial for the EMPIS to possess certain decision and analysis functions for executives in the mobile environment. Included should be basic spreadsheet functions such as adding a selection of data cells, accounting formulas which can be inserted just by selecting from a list, and charting. Since Rockart and De Long [34] stated that mastering spreadsheet software takes too much time for most executives, it may be important to implement just some of the more frequently applied spreadsheet functions. Such functions would assist the executive in what-if scenarios, and would to some extent help forecast future trends.

Rapid decision making has become more important with the increase in competitiveness and faster communications make the time span of implementing important changes critical [8]. In a time when many executives are being armed with notebook computers and cellular phones, becoming what has been termed "road warriors", they have been equipped to make important decisions anywhere, at any time [22, 35, 42]. In dynamic and uncertain environments, it has been reported that effective firms make strategic decisions quickly [10, 31]. Thus we envisage that the advanced technology of the EMPIS can lead to a more rapid identification of problems and opportunities and can reduce the time required to make decisions. With the powerful computing infrastructure that has been developed over the last 20 years, and with the advances in wireless communications, the concept of a highly integrated *mobile office* is now very much a reality. The idea is essentially to incorporate the advances in mobile telephony, computing, communicating, decision making support and information retrieving, into one unit.

Section 2 addresses the concept of the EMPIS as an analysis and decision making tool. Individual decision scenarios will be examined, as well as various forms of data analysis which support the decision making process. Correspondingly, Section 3 deals with issues group decision scenarios. Section 4 includes analysis of security and anonymity issues in a mobile environment. The problems associated with eavesdropping and mobile host location will be indicated. Section 5 focuses on concluding proposals for the EMPIS mobile environment communication architecture. Section 6 includes a short summary.

2. EMPIS As An Analysis and Decision Support Tool

According to a recent study by Chi and Turban [2] on distributed intelligent EIS, the following capabilities are desired for decision support:

1. Drill down; an intelligent agent can identify what is going wrong, saving drill down time,
2. Highlight problem indicators,
3. Ad hoc analysis,
4. Information presentation in a hierarchical form,
5. Providing management with exception reports,
6. Showing trends, ratios and deviations,
7. Being organized around critical success factors,
8. Forecasting ability,
9. Filtering, compressing and tracking critical data, and
10. Supporting open-ended problem explanations.

It is obvious that executives who plan and analyze carefully and focus on facts and figures, rather than those who use qualitative or subjective information, are more likely to accept the EMPIS (cf. [10, 29, 34]).

2.1 The Notion of Decision Style

An EMPIS provided with the resources to access intelligent agents which can analyze and integrate data, and help solve complex problems, can benefit the executive because the decisions in the mobile environment can then be based on real facts and not just on intuition. However apart from the automation that the EMPIS can provide for decision making, there will always be the human aspect known as *decision style*. Decision style and its relation to strategic decision making has long been of interest to management researchers. Elam and Leidner [8] have formally defined the way in which one perceives and comprehends stimuli followed by the way in which one chooses to respond. Individual style affects the executive's approach to problem formulation, problem solving and information processing.

A big challenge to the functioning of the EMPIS in decision making is whether it can be flexible enough to cater for the four supposed decision styles: directive, analytical, conceptual, and behavioral. Executives with a directive decision style want results fast; they apply past experience and rules to analyze data. They do not ponder over vast reports or data. Using intelligent agents (see [27]), the EMPIS could be the tool to present limited but efficient and meaningful data. The analytical executive adopts a logical approach to problem solving. Large amounts of data may be queried so that the executive can analyze all possible aspects of a given problem. The conceptual and behavioral executive is social-oriented. The focus is on the social aspects of the work environment. The emphasis is more on person-to-person interaction. Perhaps in such a situation there is no time pressure; the time spent on finding a solution based on social interaction is time well spent.

This leads us to conclude that the EMPIS is of no real use to executives who fall into the conceptual/behavioral category. We believe that executives who are under time pressure to make decisions quickly will find the EMPIS of more use, rather than those who are not under time pressure. Our study [32] has strongly supported this conclusion.

2.2 Combining Data Views To Perform Analysis

Figure 1 presents the decision making process of the executive according to Chi and Turban [2]. The executive scans either his company environment or external environment (or both) for data which relate to the task at hand; the executive can from anywhere and at any time access distributed databases to pull data to the EMPIS. Conceptually the retrieved data may be arranged into one "display window" per data source. Then the executive can evaluate the data, window by window, and select those which are most relevant. A new window can be activated to contain the selected data. Analysis is both qualitative and quantitative. Are there sufficient data, and are they relevant to the task at hand? If so, the data are combined in a way that the executive can create a data "view", and charts or graphs may be produced to pictorially view the data.

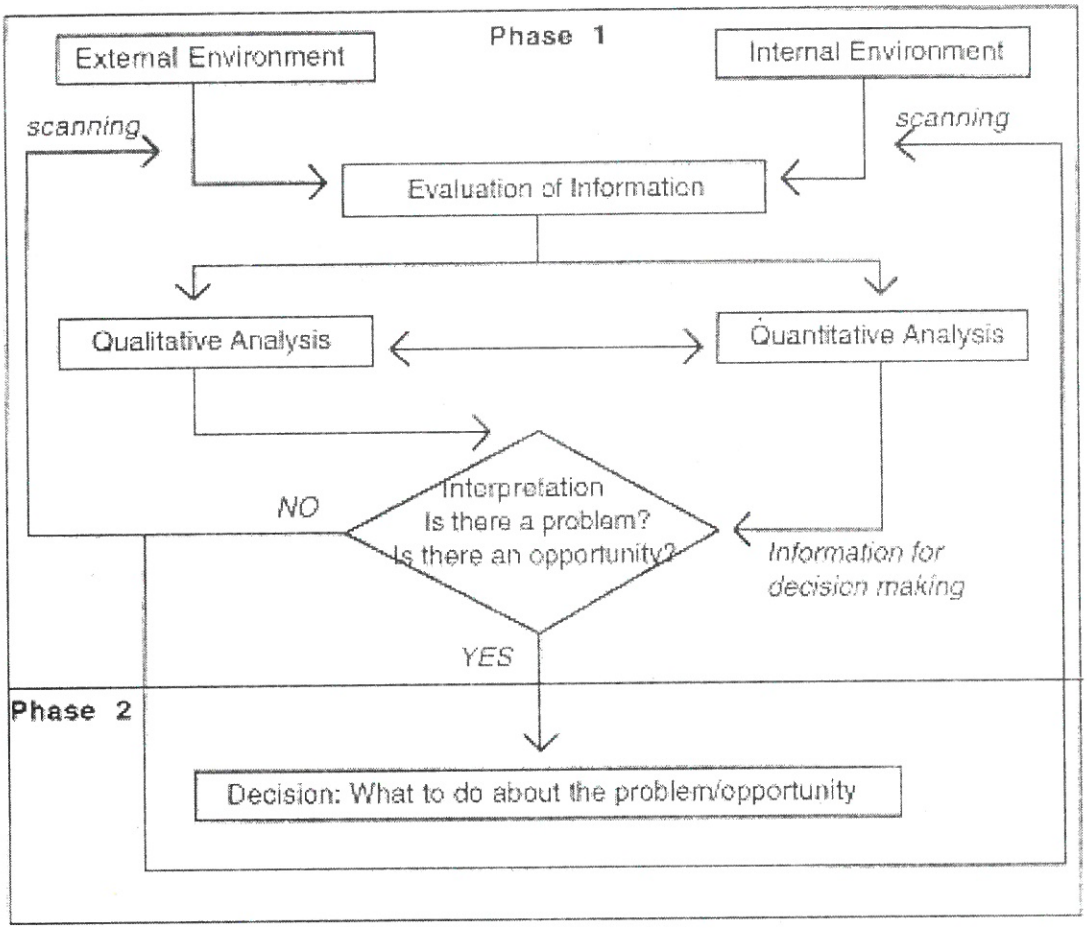

Figure 1. The Decision Making Process of An Executive

(the arrows indicate flow of information, cf. [2]).

For example, the mobile executive can pull internal sales figures for the previous quarter, and can pull competitors' sales figures for the previous quarter also. Combining both graphically into one data view can show the executive if the company is performing favorably or poorly in comparison with competitors. By providing certain functions on the EMPIS such as accounting/economic formulas and data cells, ratios and percentages can be derived from manipulating the data view; from this the executive knows that there is a problem (maybe poor company performance) or an opportunity (maybe new ideas to stay ahead of the competition), and trends and/or deviations can be shown. We also propose that there should be a facility on the EMPIS by which the executive can set a *problem indicator*. By target we mean that the executive can assign the indicator a value, e.g. setting it to 500,000 to signify that sales for this quarter must not drop below 500,000 USD. This indicator can then be set to *active*. When the executive is then performing ad hoc analysis on combined sales data, the indicator will *highlight* any deviations from the intended target.

The advantage of a combined data view for the executive is that it can give him or her a *holistic* understanding of the business. Combining text, numerical, and graphical data could highlight *trends* the executive might not have recognized with just partial data. We emphasize a graphically combined-data representation for the EMPIS for a number of reasons (cf. [4, 27, 36]). Firstly, graphs can be understood quickly. Secondly, graphs can be rotated, tilted, and adjusted to see the data in the exact perspective that best tells the story.

2.3 Ad hoc Analysis

Since the executive would occasionally query data which come from different sources, and these data must be filtered and combined into a meaningful representation (as outlined in [27]); it could be of benefit to the EMPIS if there were an *information database (IDB)* at the home server domain. This information database might be object-oriented in structure and act as a storage medium for combined data views. It would support a command language for access (perhaps SQL) or another more akin to standard English. The main idea is that combined data views, when created, are not lost, but rather they are permanently recorded as metadata in the IDB. This allows the metadata to be requeried and reused as often as necessary.

Information databases affect planning and control in several important ways. Firstly, they provide a source of raw information which can then be used by analytical executives to perform their own analysis [20, 21, 34]. Such executives could pinpoint potential problems by being able to access up-to-date information about company or employee performance and by using analytical functions provided by the IDB query language. It is difficult to accurately assess how necessary such a facility is for the EMPIS. One must consider if a mobile executive will have the task of analyzing company performance [38, 39, 40]. Perhaps only the CEO will have that task which is carried out in the head office. Perhaps a mobile executive who is in charge of a large sales territory and who is often travelling from location to location to assess sales performance, could use such an IDB-access function on the EMPIS to evaluate the forecasting capabilities of his or her sales managers. Using a graphical analysis interface on the EMPIS, the executive could at any location track sales per district, and show historically what each manager had forecast, the sales budget, and the actual sales. When this information is formatted into a graphical representation, the executive could see the forecasting tendencies of the district managers. The advantage of being able to produce these results "on location" is that the executive could confront the managers with graphic evidence of their performance and further monitor, project, and plan the future progress of the particular sales territory.

2.4 EMPIS-agent Interaction

Figure 2 conceptually illustrates a *decentralized network of agents* which interact and combine their resources via a coordinating agent to solve complex problems. The agents do not have to be on the same location. Since the EMPIS we propose should be "internet-ready", it follows that very distant databases (perhaps on the other side of the globe) would occasionally be queried, perhaps in a situation where the executive accesses the databases of a company subsidiary. The agents could physically be located at the subsidiary, and they could respond to signals from the geographically distant EMPIS. Knowledge bases containing case and rule bases, and databases, could be accessed via the Internet. Fast access to these knowledge bases is critical, and the Internet, we feel, can provide speed required, at least in the very near future (see [9, 12, 15, 17, 27, 30, 33, 42]). The automation of locating and processing data that the Internet can provide is a distinct advantage of the EMPIS. The Internet could allow the EMPIS to activate knowledge processing agents no matter where they are located.

The activated knowledge processing agents (see Figure 2) would retrieve and organize data from the databases, and then refine the data into a meaningful interpretable form. The refined data would then be transformed by a presentation engine perhaps into Hypertext Markup Language (HTML) format which would then be transmitted back to the EMPIS home server. The HTML document might be rearranged there to reflect the type of work the executive is engaged in. From there, where the current location and identity of the EMPIS is stored, the same data are forwarded to the mobile support station EMPIS proxy, and finally wirelessly transmitted to the EMPIS itself. It is difficult to approximate how long all this processing and transferring of data would take today. As already mentioned, the mobile executive does not like to wait too long for results, but we are confident that the Internet could soon provide the solution to the requirement for rapid data transfer.

A HTML interface format for the EMPIS is a worthy consideration in terms of utilizing information processing agents. As mentioned, HTML allows raw data from different sources to be combined, refined, and presented in a meaningful manner to the executive. Futhermore, depending on the type of work the executive is involved in, it is a relatively simple process to rearrange HTML data into a form which reflects the particular field of work of the executive.

2.5 Concluding Remarks On EMPIS As An Individual Analysis and Decision Support Tool

To conclude the section on individual decision making and analysis, we believe that a decentralized network of agents which interact and combine their resources via a coordinating agent to solve complex problems will be a great challenge in the field of decision support tools.

decision making processes. We shall discuss that in the next chapter.

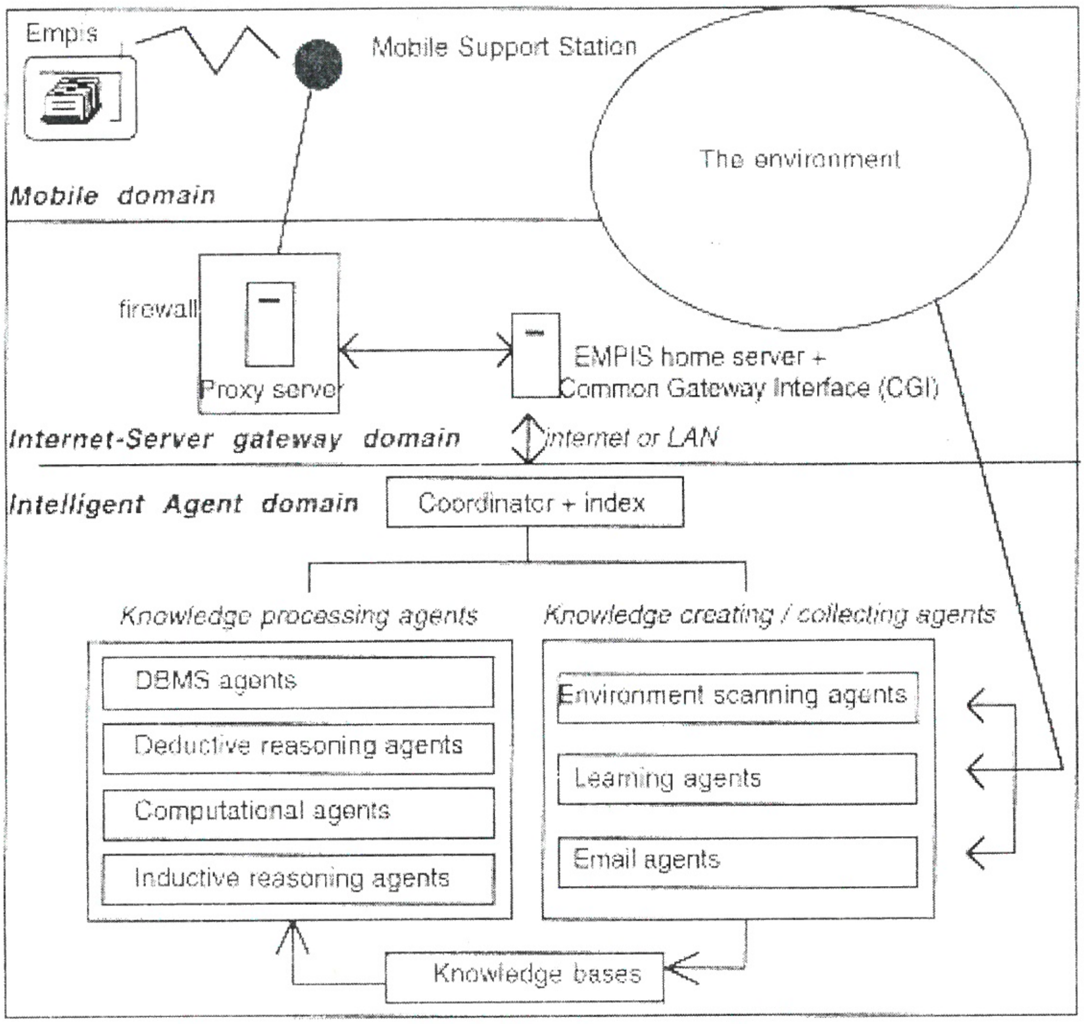

Figure 2. Our Conceptual Representation of EMPIS-Intelligent Agent Interaction (adapted from [2])

The agents do not have to be on the same location. The remote agent system would sub-divide the problems and submit partial results which when combined would present a solution for the executive. How successfully this can be designed and implemented remains to be seen. It is probable that intelligent agents can combine data from varying sources into one EMPIS view to allow the mobile executive make ad hoc decisions on the move. We could probably say for certain that an EMPIS graphical interface will be necessary for decision making and analysis; it is graphical data analysis that has been used in EIS systems for almost a decade now and it is what executives have become accustomed to using.

Even a greater challenge in the field of decision support tools will be the support to group

3. EMPIS As A Group Decision Support Tool

3.1 Group Decision Making

In this Section we outline a conceptual group decision system as defined by Csaki et al [5], whereby one or more decision makers from different fields but with a common interest have the task of ranking certain alternatives that have been previously given and characterized by a finite set of criteria or attributes. It may be possible that the mobile executive might want to seek the advice or assistance of other executives, without having to all meet in one location, but rather utilize the EMPIS to provide the interface upon which the decision criteria are displayed and manipulated. The Hungarian WINGDSS project has put forward such a group decision concept which provides a final evaluation for every alternative, ensuring a ranking according to the final scores.

imagine that a supervisor in the home domain can organize such a group effectively and quickly. It would be more realistic to see the executive who initiates the group decision session to take the role of the supervisor, since it is he or she who can contact the decision makers quickly via EMPIS email or voice call, and to

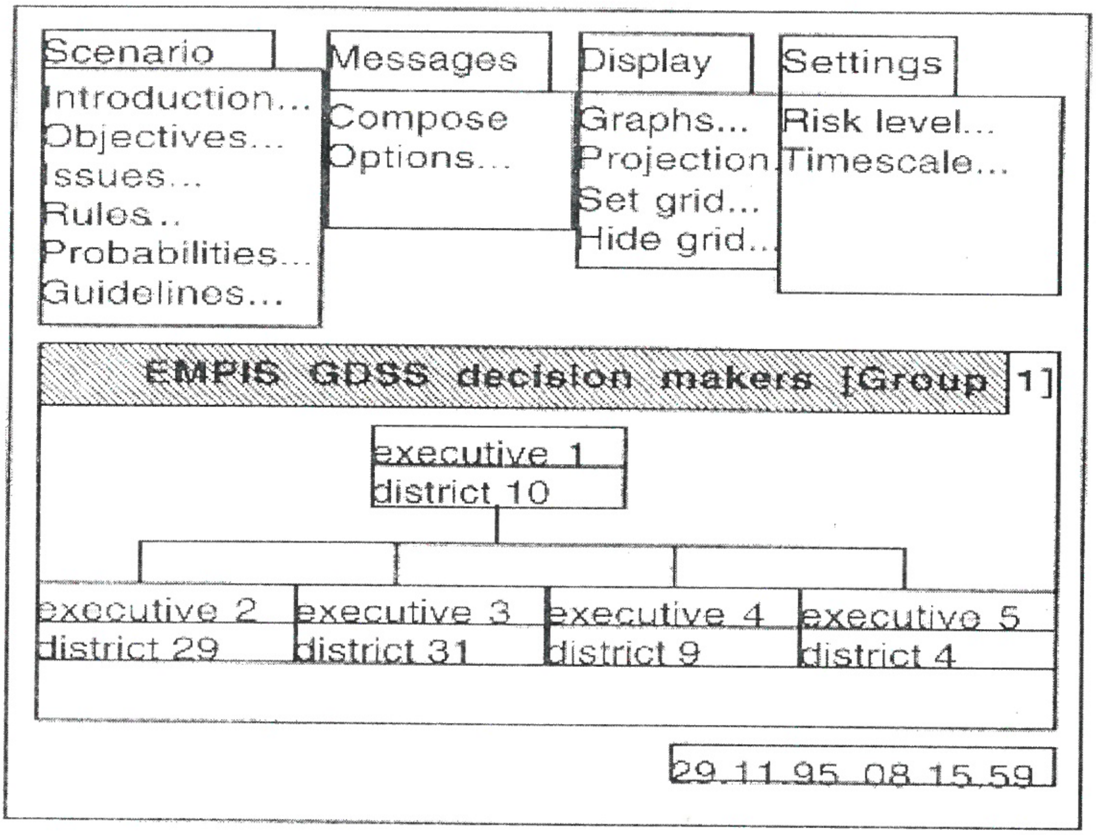

Figure 3. Some Probable Components of A Group Decision Process

According to Csaki et al [5], *idea organization* is a key issue in a decision process. In WINGDSS the problem criteria are hierarchically organized as a tree. The tree root is the problem itself, and the tree branches into subproblems, with the leaves being the non-decomposable criteria. The decision makers assign a *preference weighting* to leaf criteria. Then beginning from the lowest level of the criterion tree, the combination of the preference weights and scores at the leaves results in *scores* at the higher level nodes. The preference weight scoring continues up through the levels until at the root where the final score to each solution alternative is calculated.

An appointed supervisor arranges the decision group, defines the voting powers and authorities of the decision makers, and assigns a login code and password. Who the supervisor should be is unsure; in a mobile setting it is difficult to prearrange to set aside a period of time for the decision session. The initiator could also be the one to assign a login and password to the participating decision makers. The data to be used in the decision process can be filtered from relevant databases by prescribing a *threshold value* [5]. The data may be categorized according to *financial*, *professional*, or *functional* data. Data records satisfying the threshold value will then be extracted.

After login and receiving the filtered data, the decision maker starts the individual evaluation process. We suggest that there may be a common white board on the supervisor's EMPIS to whom each decision-maker will transmit his or her choice. The white board can be seen simultaneously by all the decision makers, and the decisions are displayed as they arrive to the supervisor EMPIS in the same way that multiple messages arrive to users of the Internet real-time 'chat' system [3, 22, 26]. The decision votes are then calculated and the result displayed. Some necessary components of a group decision process are outlined in Figure 3.

According to Csaki et al [5], WINGDSS has been successfully applied to the Tender Bureau of the Hungarian Telecommunications Company, the Hungarian Ministry of Welfare, and the Ministry of Environment and Research Policy. Decision makers have used WINGDSS to score certain aspects of financial plans. An experiment with appraising hotels has been carried out for the Hungarian State Property Agency.

3.2 Coordinated Decision Making

There has been much discussion in EIS circles in recent times about the notion of *intelligent agents*. This has centered mostly around non mobile EIS, but certainly some of the concepts and finding may also be applicable to the EMPIS. *Distributed decision making* (DDM) is a computerized coordinated decision making effort among communicating individuals who possess some specialized knowledge and can process the knowledge in a manner that contributes to performing some intelligent tasks in the decision process. Distributed problem solving has been defined as the cooperative solution of problems by a decentralized and loosely coupled collection of knowledge sources [2]. In a mobile environment using GSM or infrared signaling, it can be possible for executives to log onto a group alias via a cellular phone; the alias would have been created earlier on the basis that the executive group occasionally combines their expertise to perform group decision and analysis.

Executive decisions are very complex and therefore the problems should be partitioned into *subproblems* if possible (Figure 4). The subproblems can then be analyzed by individual executives who contribute their results to a common solution. The process should be as automated as possible. The executive is not concerned with the background processes, only the result matters. Thus it is logical and practical to propose an EMPIS which can make use of a decision support system with multiple expert systems. Intelligent agents can help the EMPIS in retrieving, filtering and presenting data. It is difficult to predict where the agent system should be located - on the EMPIS or at a home server. This would depend upon the logical complexity and operating demands of the agent system. In any case, we must contend that this process involves many tasks running concurrently, and automation of these tasks can be done only if an agent system is implemented. The notion that the EMPIS could access an agent system to perform decision making and analysis brings us to the next section which deals with the concept of task-sharing. The notion of group decision making will be further addressed later.

3.3 A task-sharing Approach To Problem Solving

Task-sharing can be interpreted as decomposing

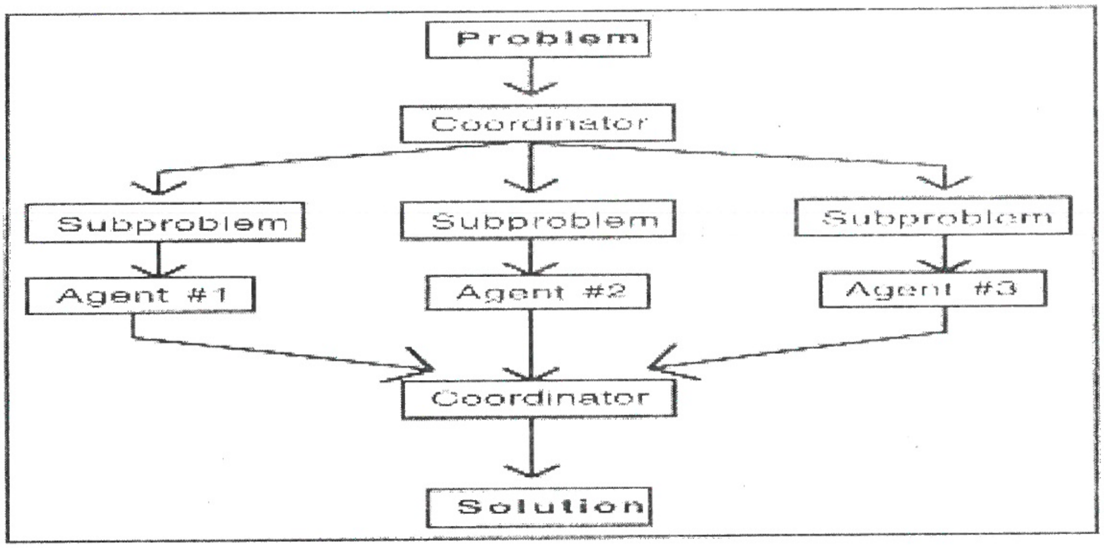

Figure 4. Task-sharing - Problem Decomposition (cf. [3])

a problem into several smaller subproblems (Figure 4). Each subproblem is channeled to one agent where computational functions occur asynchronously, and the subsolution is then submitted synchronously with the other agents to an electronic coordinator, where the final solution is calculated. Again, we cannot determine where this coordinator should be located (locally on the EMPIS or remotely at the home servers). A protocol for allowing agents to submit *bids* for tasks has been suggested by Chi and Turban [2] whereby any agent that receives a task announcement message can reply with a bid, which is basically an indication on how the task is to be accomplished. Then the coordinator that announces the tasks collects bids and awards the task to the bidder with the highest bid.

Task-sharing can be especially appropriate to a situation where a problem must be broken down in a hierarchical manner, or levels of data abstraction. These problems can be subdivided into subproblems. In other words, the approach adopted should be to "divide and conquer" the problem. Many of the problems which executives face with in their daily routines are of this nature.

3.4 A result-sharing Approach To Problem Solving

Result-sharing is a "partial-result" agent interaction method whereby individual agents submit a result which can be used by another agent. The computed result achieved by one agent is used as input to the calculations to be computed by another agent. There is no explicit problem or subproblem hierarchy, in contrast with task-sharing. A coordinating agent acts as a receiver for the partial results computed by the other agents. Such agents may be database query engines, text searching engines, or trend and deviation indicators. These agents submit their partial result to the coordinator which then forms an overall plan for problem solving. For example, the mobile executive may be required to combine information of a textual and numerical nature from a variety of sources; a query may be submitted to a DBMS agent and an environment scanning agent, which then submit their results to a coordinator agent. The coordinator arranges the partial results into a single meaningful representation which can then be transmitted back to the EMPIS via the home-mobile gateway, i.e. *the air interface*. The biggest challenge is to how to manage and control the interactions of various agents.

Result-sharing has been stated by Chi and Turban [2] to be particularly appropriate for *sequential decision making*. For example, the executive can make a decision on making a business deal only when it is decided that the business partner is suitable, the financial benefits are acceptable, and the deal requirements will be met in the future. Result-sharing is appropriate for problems where results achieved by one agent contribute or constrain those achieved by another, and where the system is driven by the combining of partial results to finding a solution to a problem.

3.5 Concluding Remarks On EMPIS As A Group Decision Support Tool

To conclude the Section on group decision making and analysis, we believe that task-sharing and result-sharing agents may one day be able, in a mobile setting, to help executives make decisions (cf. [8]).

Although the WINGDSS concept [5] is interesting, we doubt, however, that it is of real direct applicability to the EMPIS because, from a human viewpoint, we doubt if mobile executives would be willing to allow other executives know what their business is all about. Therefore from a practical viewpoint, it is currently difficult to imagine a mobile "common decision white board". The remotely located software which must run the white board wirelessly would have to be very complex, and probably it would involve too many data being transmitted back and forth.

It is yet difficult to predict what will come since these are early days in mobile EIS. However, noting the amount of activity occurring in mobile computing laboratories worldwide, we may not have to wait very long.

All decentralized computing creates security problems. We shall analyze them in the next Section.

4. EMPIS Security and Anonymity

The packaging of executive functions into a pocket-sized mobile entity would be the biggest asset of the EMPIS; the executive would no longer be confined to the desktop or briefcase-sized notebook computer [18, 37, 43]. It is apparent that a laptop computer is taking that role for at least the near future. In any case, the mobility strength raises a number of important security issues. In a mobile computing environment, it is absolutely necessary to protect knowledge about the movements and activities of the EMPIS against eavesdroppers; most people who own a cellular phone have heard at one time or another about spys scanning for cellular calls. Many of these stories are true, although now the digital GSM cellular system is quite resistant to current cellular scanning software.

Since we envisage that the EMPIS will function in conjunction with a cellular phone, we must consider the protection advantage GSM can offer to EMPIS data transmission. Herzberg, Krawczyk and Tsudik [13] state that in the ideal mobile computing environment, no entity other than the user and a responsible authority in the user's home domain should know either the real identity or the current location of the mobile user. Since it may be difficult, if not impossible, to achieve the absolute ideal situation, we can at least strive to achieve limited but practical anonymity using standard cryptographic techniques, and by aliasing [1]. These are the methods examined in the following Subsections.

4.1 The Home-foreign Domain Scenario

Let us imagine a typical EMPIS situation; the mobile executive has just completed a business contract in domain X, and then commutes to domain Y for further business. Let us also assume for this purpose that the EMPIS is registered in a geographically distant domain A. The executive requires services from or through the local (foreign) domain A. The local domain must authorize the EMPIS and then, in return for services, be paid. To achieve this, some method must exist whereby the local domain can match the confidential EMPIS personal-ID with the personal-ID record at the home domain. In many of the mobile computing research projects worldwide (see Herzberg, Krawczyk and Tsudik [13]), there is an agreed assumption that every user has a *home* location where this user is registered as *indigent*. However, this assumption may not hold in the future. For example, a cellular phone user, instead of subscribing with a particular communications provider, may simply obtain electronic cash from a vending machine or kiosk, and spend it piecemeal on making calls from any location. If this situation becomes fact, it will result in *homeless* mobile user environments. Herzberg, Krawczyk and Tsudik [13] believe that at some point in the future homeless mobile users will exist.

4.2 Anonymity Defined

According to Asokan [1], anonymity has two aspects:

- *anonymity of location* deals with keeping an entity's movements and whereabouts confidential, and
- *anonymity of data origin and destination* deals with keeping an entity's activities confidential.

From the viewpoint of the EMPIS, the latter aspect would seek to prevent an onlooker from associating the EMPIS with messages sent from/to it, or with the communication sessions in which it would be a participant. The only breach of anonymity acceptable to the EMPIS should be the revelation of its identity to a data server for the purpose of authentication (see [23]). The actual true identity could even be hidden by a *traveling alias* from the home domain [13], in order to prevent the revelation of the actual EMPIS identity.

In spite of the interest mobile computing is generating, there has traditionally been no interest in addressing anonymity in fixed entity and wired network environments. This fact further extends to the Internet Engineering Task Force (IETF), which has made no provision so far for anonymity. One exception to this are the so-called *anonymous remailers* which have been gaining popularity on the Internet (an anonymous remailer is a clearing house for anonymous newsgroup postings and regular electronic mail [13], cf. [17]). Asokan [1] asserts that provision of anonymity is tightly coupled with the architecture of the rest of the system. For example, providing anonymity of the network layer identity will be of little use if the routing protocol uses re-direction. An onlooker who has access to a router elsewhere on the system can determine the whereabouts of a mobile entity by trying to send a message to it. Therefore we must assume that providing anonymity for the EMPIS should be developed during the design phase of building the EMPIS.

The anonymity problem has been addressed by GSM in Europe and CDPD in North America. We shall discuss GSM anonymity in Subsection 4.4.

4.3 The Concept of An EMPIS Traveling Alias

Above we proposed that a traveling alias could be provided to hide the true identity of the EMPIS. As already stated, the mobile executive who moves from one domain to another may want to obtain services which must be paid for. To be able to acquire these services requires the EMPIS to submit a personal identity. The host domain may not necessarily need to know the actual identity of the EMPIS; if a service does require the actual identity, then perhaps the EMPIS home domain can secretly transmit the identity to the remote domain. In any case, a traveling alias is perhaps the best option.

Herzberg, Krawczyk and Tsudik [13] suggest that there should be a *frequently changing* alias. We propose that the EMPIS itself, or the EMPIS home domain, should have the ability to frequently change the traveling alias. The reason behind this proposal is that if the EMPIS alias is of a semi-permanent or long term type, and if a hostile intruder cracks the alias code, then, as suggested in [13], the identity and the movements of the mobile user would be compromised on a long-term basis. We envisage that since the EMPIS will function in conjunction with a GSM cellular phone, and the GSM phone offers some basic security by virtue of passwords and the Personal Identification Number (PIN), the sophistication of the GSM phone may be sufficient to generate frequently changing aliases (perhaps a new randomly generated alias every minute or so) within a tamper-proof module, either at the EMPIS home domain or on the EMPIS itself.

4.4 Anonymity in GSM

In the GSM cellular system, the mobile device is always under the control of the nearest Base Station (BS). When the mobile device migrates to a neighboring *broadcast cell*, the neighboring BS takes over the handling of the unit; this is known as *handoff*. GSM wirelessly protects the identity of the mobile device and its home location by transmitting them to the local BS from the previous BS (see [26, 42]). Then as Herzberg, Krawczyk and Tsudik [13] point out, the mobile unit *registers* with the local BS and receives a Temporary Mobile System Identifier (TMSI). Therefore, the TMSI is used as the authentication code whenever the mobile device communicates with the BS (cf. [23]). Then when the mobile device migrates on further to another broadcast cell, it transmits the TMSI and the Location Area Identifier (LAI) of the previous BS. In this way, the new BS receives the actual identity of the mobile unit and the LAI from the previous BS. If the previous BS cannot be contacted, the current BS can stall and request the actual identity and home location of the mobile device. This generally provides adequate mobile anonymity.

4.5 GSM Limitations

As Herzberg, Krawczyk and Tsudik [13] assert, the BS *fall-back* process is open to attack from a hostile intruder who masquerades as a BS. The intruder would claim to have no contact with the previous BS in order to get the TMSI and LAI. Herzberg, Krawczyk and Tsudik [13] go on to say that in this situation most implementations would be forced to reveal the International Mobile System Identifier (IMSI) of the mobile unit. Another possibility for hostile intrusion occurs during the *registration* of the mobile device with the current BS. This authentication process involves the IMSI being transmitted in the *clear* over the air link. Another possibility for hostile intrusion occurs when the GSM mobile state *synchronization* is lost. The GSM BSs are designed to maintain the mobile state, even when the mobile device has migrated to a distant BS.

4.6 Time-based Aliasing

Herzberg, Krawczyk and Tsudik [13] have also proposed a *time-based* aliasing. The theory behind this is that the "world" is partitioned into administrative domains. Every mobile device has a home base in at least one domain, and every domain has at least one Authentication Server (AS). The following methodology proposed by Herzberg, Krawczyk and Tsudik [13] could perhaps be applied to the EMPIS.

Every domain *Dx* selects a domain-wide time interval *x*. (where x is expected to be relatively coarse, e.g., an hour, a day, or longer). When a user *Ux* whose home is domain *Dx* migrates to another domain *Dy*, he first needs to be authenticated and a *temporary record* must be created for him in *Dy* so as to facilitate subsequent accesses in *Dy*. This temporary record in effect becomes a temporary "home" for the mobile device so that it does not have to contact the home domain upon every data access. The authentication and temporary record establishment procedure can be abstracted as shown in Figure 5. The exact format of the authentication flows is not important in this context. Regardless of the authentication specifics, the identity of *Ux* must be somehow communicated to *ASx*. Since *Ux* cannot communicate with *ASx* directly, all communication must flow through the local authority *ASy*.

line as well as *in advance*. The alias tables may require considerable storage space, but advantage is gained in that the protocol is strengthened.

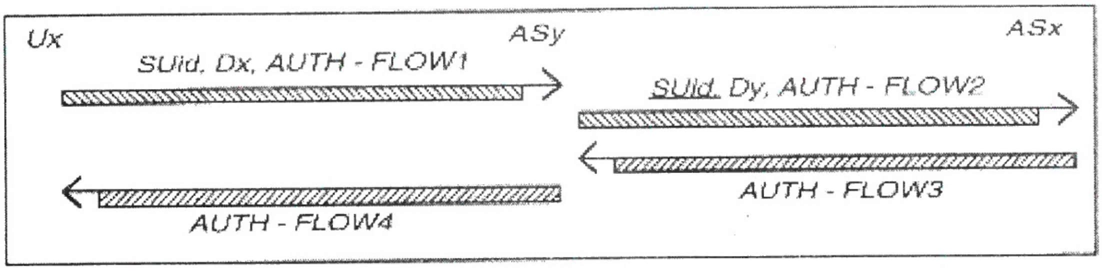

Figure 5. Sample Mobile User Authentication Protocol (modified from Herzberg, Krawczyk and Tsudik [13])

The first authentication flow must include a *user identification field*, denoted by *SUid*. Similarly, the second flow (from *ASy* to *ASx*) must also include some form of user identification, denoted by <u>SUid</u>. We can assume <u>SUid</u> to be an encrypted version of *SUid*. *SUid* is computed as:

$$SUid = F(U, Tu, PWu)$$

where F is a strong one-way function, *Tu* is the current time rounded to the nearest *x* value, and *PWu* is the user password which is entered into the mobile device. Herzberg, Krawczyk and Tsudik [13] further point out that for a smartcard-bound user, the *PWu* can be either a strong key stored within the smartcard, or a combination of the smartcard's key and the user's password.

It is important to note that *SUid* is unintelligible to *ASy*. The only information *ASy* is able to obtain is that the mobile user is registered in *Dx*. In the second flow, *ASy* transmits *SUid* along with authentication information to the mobile user's claimed home domain authority *ASx*. We think that the crucial issue is how *ASx* determines that *SUid* corresponds to the locally registered *Ux*. It does so by maintaining an up-to-date table which, for each native user, lists the corresponding *SUid* value. This translation table is computed for every time interval x. Since *ASx* already stores the values of *U* and *PWu* for every mobile user, it has all the necessary information to compute up-to-date translation tables.

Another important point is that the *SUids* are not dependent on the mobile user's current location. The translation tables can be pre-computed *off-*

4.7 One-time Aliasing for An Intelligent EMPIS

We propose that if the EMPIS itself will possess considerable computational power as opposed to downloading computational utilities from the home server, the EMPIS could locally store secure strong keys and state information in a tamper-proof module. For added security, *one-time aliases* could be computed on the EMPIS which would mean safety from intruders scanning the air link. The one-time alias is generated by encrypting the name of the EMPIS using a strong secret key. The encryption should be calculated using a *random* function, so that each encryption produces a different result. Only the home domain knows the EMPIS IMSI. We propose that perhaps the IMSI should not at any time be transmitted to the EMPIS, since real identity transmission is in the clear over the air link, but rather an alias for the IMSI should be used. Again this would protect the EMPIS from hostile intrusion.

If it should be preferred that the encryption takes place in the home domain, the home domain authority should be free to change keys and encryption functions at random without impact on the EMPIS. In other words, the encryption process should be hidden from the EMPIS. We should also point out that the home domain authority should possess an *alias-history* table so that it can trace back to older EMPIS aliases for verification. In any case, the EMPIS one-time alias should change with each move to a new broadcast cell, or even with each access to a network server.

4.8 Shared Key Encryption

Molva [23] has proposed that a mobile entity could use a traveling alias (as also suggested by Herzberg, Krawczyk and Tsudik [13]). Only the mobile entity and the home domain would know the mapping between the traveling alias and the real identity. The alias should be *short-lived* to prevent long periods of using the same alias which would be very insecure. The aliases would be frequently changed by mutual agreement between the mobile entity and the home domain authority. To achieve this, the mobile entity state and the home domain state must be synchronized. We propose that the synchronization could function in the same way that the GSM system synchronizes voice data packets for cellular phones.

4.9 Concluding Remarks On EMPIS Security and Anonymity

We have examined various solutions for providing a mobile entity with anonymity. The aliasing proposals are realistic and can provide the necessary protection required. Anonymity for the EMPIS could be provided by linking it to the security offered by the GSM system. The GSM system will of course be further enhanced in terms of security as time goes by, and perhaps the EMPIS could further have a GSM-compatible key encryption feature which would hopefully make its anonymity and security impenetrable. In the important and often confidential work of the mobile executive, we feel that EMPIS anonymity and security is absolutely vital. Also several other problems must be solved in this area, as indicated e.g in [6, 17, 25].

In the following Section we will further consider some proposed mobile environment communication architectures - one of which was briefly illustrated by O'Donoghue, Puuronen and Savolainen [27]. We will reintroduce terms such as GSM, proxies, broadcast cell, gateway, caching, and handoff. We will introduce new terms such as routing, bandwidth, latency, fault tolerance, packet radio, infrared, asynchronous transfer mode (ATM), and Personal Communications Networking (PCN).

5. Proposals for the EMPIS Mobile Environment Communication Architecture

O'Donoghue, Puuronen and Savolainen [27] illustrated what the EMPIS mobile communication scenario might look like. This was to offer a general introduction to the mobile computing environment. Now we will examine the mobile environment more closely. We will look at the problems facing the EMPIS by unpredictable connectivity, low bandwidth, and high latency, and the solutions proposed for these problems (cf. [30, 41]). We will look at the advantages GSM and Infrared can offer to the EMPIS. It is hoped that this part of our study will help the reader gain a greater understanding and a more holistic view of the environment in which the mobile executive will use the EMPIS for routine daily tasks.

5.1 Routing Challenges in An Ad hoc Mobile Environment

Johnson [14] has defined an ad hoc network as a collection of wireless mobile hosts forming a *temporary* network without the aid of any centralized administration or standard support services. This definition leads us to the notion that it may be necessary for the EMPIS to be able to exchange data with another EMPIS, without the transmission propagation aid of home domains. Since we have decided that the mobile executive will be exchanging broadcast cells frequently, and will meet clients and business contacts irregularly, it may be desirable to have a routing protocol which would allow a group of EMPIS devices to communicate by mutual support. We can gather from what Johnson [14] states about a temporary network that mobile executives would meet under circumstances which were not explicitly planned for, and in a setting where there might be no connection to a standard wide-area network such as the Internet.

Such settings may be chance meetings in an airport lounge, in a train, or in a hotel ballroom for a conference or workshop. Figure 6 illustrates what could be an ad hoc network of three EMPIS devices, perhaps side by side at a workshop. It proposes that if mobile C is not within range of a perhaps infrared transmitter of mobile A, and if C wants to transmit a data packet to A, it could enlist the services of mobile B which overlaps the infrared range of A. Johnson [14] goes on to present that the number of network 'hops' required may be more than the one hop illustrated. However, the uniform transmitting range of the mobile entities illustrated in Figure 5 may not represent the reality of transmission failures or unequal mobile entity proximities. Johnson is not in favor of periodically sending routing updates between the mobile entities for a number of reasons:

1. He asserts that routing updates would waste network bandwidth. Regular routing update signals in a setting where many mobile entities are within transmission range would consume each other's network bandwidth. We believe that while this may currently hold true, there may in future be a very high bandwidth available which would make this assertion unnecessary.

2. He asserts that routing updates would consume battery power; transmitting a data packet over the air link in effect launches a portion of battery power into the air link. This assertion may be more seriously taken than the former. Battery technology development is comparatively slow in comparison with computing innovations, although battery longevity is improving all the time.

3. He asserts that conventional routing protocols are not designed for the dynamism of ad hoc networks. We maintain that mobility of executive functions is the very essence of the EMPIS, but convergence to routers after changing geographic location may be too slow to be efficient and secure for data transmission. This is a problem to be addressed.

5.2 Application of ARP To the Mobile Entity

Johnson [14] has suggested that the problem of routing may be divided into *route discovery* and *route maintenance*. Translating this suggestion to an EMPIS scenario means that the EMPIS must discover a suitable route in order to send and receive data packets, and this route must be maintained until such time as it becomes inefficient or the EMPIS moves to a new location. Johnson [14] looks to the Internet Address Resolution Protocol (ARP) to seek a solution. ARP is designed for dynamically translating a host's network protocol address (such as an IP address to its MAC address in the Ethernet, see Postel [30]). A host attempting to translate another host's address broadcasts a query packet onto its local network, which is answered by the target host giving its MAC address; other hosts on the local network receiving the query do not reply. The returned MAC address is then cached by the host for use in sending future data packets to this destination.

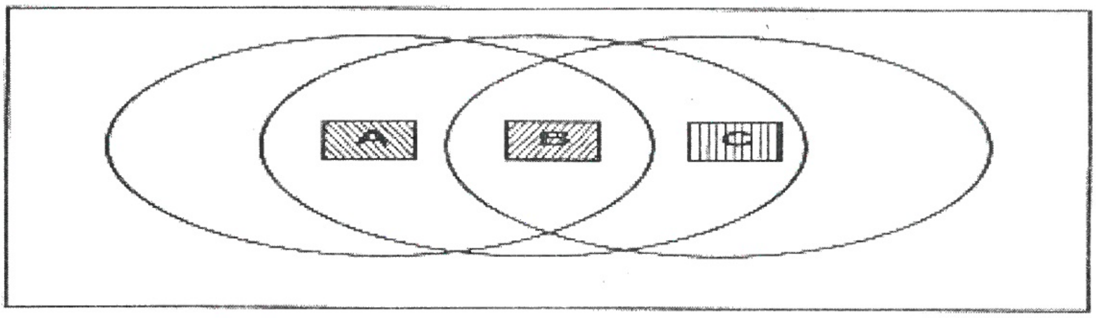

Figure 6. An Ad hoc Network of Three Mobile Hosts (modified from Johnson [14])

A proposed application of this protocol to a mobile network is that a simple ARP query can be used to discover a route to the target mobile entity which is within transmission range of the sender. The returned MAC address can be used directly to transmit data packets to the target entity. No periodic routing updates are required, saving bandwidth and battery power. Such an application to the EMPIS may be feasible.

Another proposed application of ARP could be to send a request packet and propagate it using some form of flooding, so that the packet could reach other mobile entities beyond the sender's transmission range. As the request propagates, each mobile entity adds its own address to a route being recorded in the packet, before retransmitting the request onto other mobile entities within broadcasting range. If an entity finds its own address already recorded in the packet, it discards the copy of the request and does not propagate the copy any further. To eliminate mass duplication of these request copies, each request could contain a unique *request-id* from the original sender. Each mobile entity could have a cache containing the request-id and sender address of recently forwarded requests. If it has already propagated the exact same request-id and sender address, it dumps the most recently received request without further propagation.

In applying such a proposition to the EMPIS, the EMPIS could have such a cache containing request-ids and sender addresses. In effect, the cache maintains the route list. The EMPIS cache would store routes discovered so that it could send future data packets to that same destination. Caching would reduce the protocol overhead. Also since we can assume the EMPIS wireless transmissions to be broadcast transmissions, the EMPIS could learn new routing information from the route contained in received packets. A locally moduled EMPIS 'route learning' agent could perform this function.

5.3 The Relevance of Bandwidth To EMPIS Communication

In the world of mobile computing research, the term bandwidth has received much attention due to its critical implications for the future standards of mobile wireless connectivity [7, 9, 15, 16, 33]. This critical importance lies in the foresight that mobile computing is entering a new era where data transfer will be measured in billions of bits per second, rather than in the millions of instructions per second of current computers.

Bandwidth is communications power. As Gilder [12] states, bandwidth is the capacity of an information channel to transmit bits without error in the presence of noise. In fiber optics, digital signal processors, and wireless communications, bandwidth will expand from five to one hundred times as fast as the rise of microprocessor speeds. We may consider the wireless communication capabilities to be of greater importance for the functioning of the EMPIS, rather than its processing power. It may be that bandwidth will be more relevant to the EMPIS broadcast cell base stations and the home-domain servers rather than the EMPIS device itself, since it is on these locations that the switching and routing of data to and from the EMPIS will occur. Now we will examine proposed methodologies for handling the enormous data capacity gains from increasing bandwidth.

It is hoped that eventually the bandwidth explosion will enable interactive multimedia and video to be transported on radio frequencies. The EMPIS architecture should take advantage of such technology. Perhaps in the case of EMPIS real-time video, about which we discussed earlier, the necessary video handling algorithms (see Gilder [12]) could be fixed into the EMPIS hardware. In this way the EMPIS could bypass the time-consuming tasks of retrieving software instructions and data from memory. Gilder [12] statistically supports this methodology by stating that such hardware chips could perform their functions at least one hundred times faster than chips which use software. Such special purpose chips can now handle the broadband heavy lifting of video compression and decompression, digital radio processing, voice and sound synthesis, speech recognition, echo cancelation, and graphics acceleration. We propose that such hardware-only chips could be designed into the EMPIS.

In O'Donoghue, Puuronen and Savolainen [27] an ATM architecture was adopted for EMPIS to include an all-fiber optic network for a good reason. We believe that the network between the home domain and the base stations should be passive (cf. Gilder [12]). A complex network loaded with millions of lines of software code cannot keep up with the efflorescent diversity and creativity among ever more intelligent digital devices on its periphery. In effect the intelligence the EMPIS would access, would be confined to the data servers. The all-optic fiber home domain-to-base station connection would be a passive but rapid data carrier.

The current assumption in the telecommunications industry is that usable bandwidth will be scarce and expensive for the foreseeable future. According to Gilder [12], wireless communications engineers had been pursuing a strategy of long wavelength and strong transmission, but they realized that this actually resulted in the bandwidth spectrum being used up. Now they are pursuing a strategy of wide spectrum and weak transmission. The idea behind this is that the more a data transmission resembles the white noise or Gaussian of bit streams, the more information it can hold. More upper bandwidth spectrum would be used (away from the lower bandwidth spectrum occupied by phones, pagers, radios, etc.) for this noiselike information.

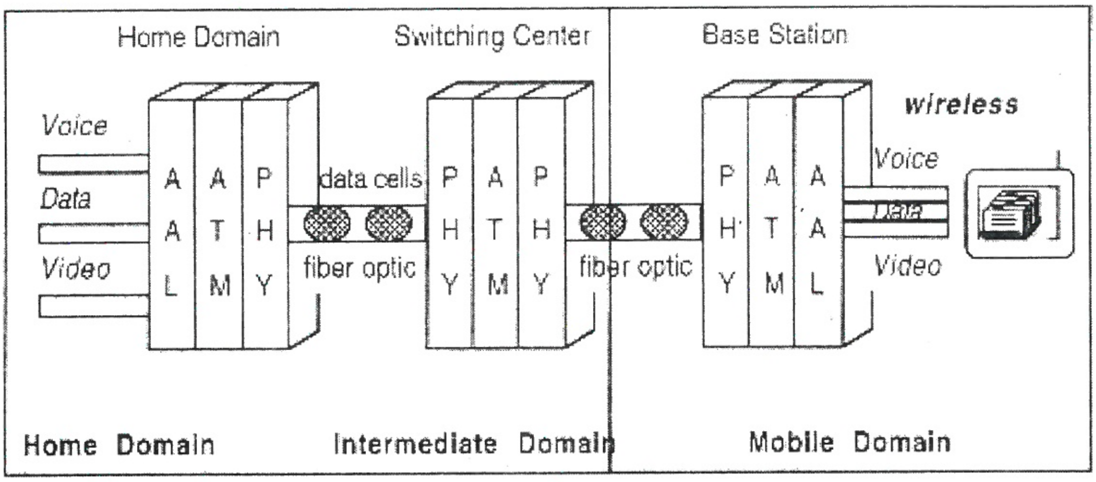

Figure 7. ATM Architecture Adapted for the EMPIS Wireless Environment

Note: AAL is an adaptation layer which inserts/extracts information into/from 48 byte payload, ATM layer adds/removes 5-byte header to/from payload, and PHY is a physical layer which converts to appropriate electrical or optical format. Cf. [44]

To conclude on bandwidth, we refer to Gilder [12] who asserts that the future of wireless communications is boundless bandwidth accomplished by wide and weak signals, moving to ever smaller cells with lower power at higher frequencies. If this holds true, it will be good news for the EMPIS architecture.

5.4 Asynchronous Transfer Mode and Bandwidth

According to Gilder [12], the most important short-term contributor to the tides of bandwidth is a new communication technology called asynchronous transfer mode (ATM). ATM packs data into cells which are all 53 bytes long, including a 5 byte address. The telephone industry chose this length as the largest possible cell which could deliver real-time voice communications. Since all the data cells are 53 bytes long, the system is not complex, and therefore the cells can be switched at high speeds through the ATM network.

We could assume that the EMPIS base stations are on this ATM network, and therefore data requests by the EMPIS would be rapidly satisfied. The beauty of the ATM system is that it can accommodate voice, video, and data, all at once. This is perhaps the primary reason why we should consider ATM for the EMPIS, since the mobile executive will often communicate via cellular phone, will participate in real-time video conferencing, and will upload and download data to and from many sources. Figure 7 illustrates the ATM system architecture, adapted to incorporate the untethered EMPIS.

As noted in the literature (see e.g. Raychaudhuri [33]), ATM has several key benefits, i.e.

1. One network-ATM will provide a single network for traffic types voice, data, and video.

2. ATM is compatible with the currently deployed fiber optic network.

3. ATM has been designed from the very beginning to be scalable and flexible in geographic distance, number of users, and access and trunk bandwidths.

4. ATM can look forward to a long architectural lifetime. The information systems and telecommunications industries focus and standardize on ATM.

5.5 Concluding Remarks On EMPIS Architecture

In this Section we have presented some proposals for the communication architecture in the EMPIS mobile environment, starting from what O'Donoghue, Puuronen and Savolainen [27] sketched as the EMPIS mobile communication scenario. We examined the mobile environment more closely, especially problems facing the EMPIS by unpredictable connectivity, low bandwidth, and high latency, and the solutions proposed for these problems. We looked at the advantages GSM and Infrared can offer to the EMPIS. Some concrete proposals were presented for the implementation of the EMPIS architecture.

6. Summary

Global organizations require mobile IT services especially for their executives and experts for several reasons (see [2, 3, 5, 12, 13, 22, 24, 33, 35, and 39]). As a concept, EMPIS (Executives' Mobile Personal Information System) is a tool to offer all the necessary mobile IT services to travelling executives, to support their everyday tasks [31, 32]. The main functional areas of EMPIS are information, communication, analysis and decision making, and office work support [27]. This paper focussed on the analysis and decision making tools, security and anonymity issues and communication architecture in Mobile Information Systems. Methods for combining data views to perform analysis, for coordinating decision making, as well as for problem solving and group decision making were suggested. EMPIS security and anonymity were studied from the viewpoints of an EMPIS traveling alias, GSM limitations, time-based aliasing, and shared key encryption. The EMPIS communication architecture was analysed from such viewpoints as routing challenges in an ad hoc mobile environment, the relevance of bandwidth to EMPIS communication, and asynchronous transfer mode (ATM).

On the basis of the requirement analysis made by Savolainen and Puuronen [32] it can clearly be foreseen that mobile computing and mobile information systems in particular will be one of the strongest development areas of Information Technology in the very near future. This paper was an attempt to help construct the EMPIS prototype and solve its several architectural problems.

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