WearIT@work: Communications for the Mobile Worker Equipped with Wearable Computing

Andreas Timm-Giel, Koojana Kuladinithi, and Carmelita Görg

Abstract— **This paper gives an overview on the requirements and the concepts to enable communications for the mobile worker using a wearable computer. Wearable computing allows a paradigm shift from working at the computer to working with the computer. The results presented are based on work performed in the framework of the wearIT@work project funded in the IST 6th Framework Programme of the EC. The project and development is based on a User Centered Design (UCD) approach and therefore considers four different user scenarios: firefighting, aircraft maintenance, car production and medical services in the hospital. The specific and general requirements on communications for wearable computing are presented and the concept and first results of integration are presented. Research topics for further investigation in the framework of the wearIT@work project are explained in the conclusion.**

Index Terms—**Wearable Computing, User Centered Design, Application scenarios, Communication Services Module**

I. INTRODUCTION

THE main objective of the wearIT@work project [7] is to achieve the break-through of pervasive wearable computing to efficiently and easily support the professional mobile workers in their daily work. wearIT@work is an Integrated IST Project (IP) funded in the EU 6th Framework Programme for Research and Technological Development. 36 partners from 15 countries collaborate in wearIT@work since June 2004. The main idea behind wearable computing for mobile worker (within wearIT@work) is the performance of their primary tasks on real objects, such as aircraft maintenance, supported by (wearable) computers instead of working on virtual objects on computers as their primary tasks (e.g. such as in software development). This completely changes the requirements on user interfaces and ergonomics. Neither the wearable computers nor the input and output devices are allowed to hinder their work usually done through the use of both hands. Therefore, generally a wearable computer is completely different from a portable computer and so differs from a PDA or a TabletPC.

In order to evaluate and promote wearable computing in realistic scenarios a user centered design (UCD) approach is followed within wearIT@work by involving partners from four different application scenarios: firefighting, aircraft maintenance, automobile production and medical services in the hospital. They are described in more detail in the next section (Section II). In each application scenario, the improvement of work flows and the acceptance of the technology are evaluated in three different phases each with improved and better adapted technology. Section III presents the wearable computing hardware and Section IV analyses the requirements on communications imposed by the four application areas. In Section V, the implementation concept for communications within the wearIT@work project during the first phase, the Show Case, lasting up to end of 2005 is presented. Section VI shows results of first performance evaluations using Ad hoc networking for interpersonal communications between two mobile workers.

II. APPLICATION SCENARIOS

WearIT@work investigates wearable computing in four different application scenarios. The requirements and scenarios of the four application fields are summarized in the following paragraphs and are available in more detail in [1] and [2].

Figure 1: Firefighter

In the *firefighting scenario* the main objective is to increase the safety of the firefighters. This can be achieved on one hand by augmenting the human senses, e.g. by having infrared cameras and head mounted displays included in the helmets and also by having temperature and position sensors integrated in the protection suits warning the firefighter in time before the temperature damages the suit. The second and even more challenging way of increasing the fire fighter's safety is by improving the coordination and communication between the firefighters including with the commander at the fire engine. Communication is extremely challenging: Reliable communications need to be maintained within buildings possibly with smoke particles from graphite and ionized plasma around the fire. The complete wearable computing system needs to be extremely robust and simple to operate.

In the *maintenance scenario* the mobile worker is supported in accessing manuals and by obtaining remote support from colleagues or experts in the vicinity or somewhere else on the world and by simplifying the documentation processes. The usability is of major importance, same as the requirement that

All authors are with the University of Bremen, Center for Information and Communication Technology (ikom), Communication Network group (ComNets): Otto-Hahn-Allee NW1, 28359 Bremen, Germany: (email: {atg, koo, cg}@comnets.uni-bremen.de)

the wearable computer including the display must not hinder the mobile worker to perform her/his task, e.g. in the wing of an aircraft. Communication-wise on one hand, the different signal propagation environments inside and outside the air craft needs to be taken into account providing interactive support and video applications. On the other hand a relatively high level of quality of service (QoS) needs to be maintained.

For the *automobile variant production* application, two different scenarios are investigated: the first is the provision of the plant management with on-line information on the production status. This however has been given a lower priority due to issues of data security. The second scenario of the automobile production which is considered in the first phase is the training of workers on a new variant or job. This should be supported by wearable computing showing training videos and at the same time evaluating the worker's work quality and training advances by sensor and context detection. This training on a new job or automobile variant has been shown to be a significant cost factor. From a communication point of view, on one side a high QoS needs to be provided between a server and the wearable computer allowing to show high quality training material (video) and furthermore a signaling link needs to be provided to the trainer to inform him on the training progress and initiating further actions.

The fourth application field of the wearIT@work project is the *clinical pathway* of the doctor. This includes the doctor's ward round visiting patients as well as surgeries in the operation theatre and meetings and discussions with colleagues and experts in the hospital and outside. The core supporting device of the doctor over the day could be a wearable computer, which either uses displays in the room, e.g. patient's TV set, to explain and present diagnostics and results but also head mounted displays are suitable e.g. to support doctors during surgeries. One important further topic addressed in this application scenario is the documentation of prescriptions, medications, and diagnostics. This should be supported by a nurse equipped with a wearable computer.

III. WEARABLE COMPUTING

Summarizing the requirements on the wearable computing hardware and the communications, it is clear that new ways of user interfacing and user interactions have to be found.

Figure 2: **Head Mounted Display (Zeiss)**

Traditional keyboards and displays are in most cases not suitable. For displaying information head mounted displays (see Figure 2) are one solution, however long term wearing comfort and user acceptance need to be further evaluated. Other solutions are to use external displays, e.g. integrated into the ambient environment, but also portable displays to be attached to walls, etc. or attached to the body or clothing, e.g. display on watch or arm.

For simple commands, actuators in the clothing can also give information to the user, e.g. an actuator on the left shoulder indicating to turn left, etc. Depending on the environment voice and audio are certainly good means to give information to the user.

To obtain input from the mobile user to the wearable or any other device or communication partner, a number of different options are available. This starts from keyboard and mouse replacements, like Twiddlers [8], gloves with keys (see figure 3), virtual keyboards (keys) projected to a wall or table and the position of the hand detected by a camera, to gyro mice, etc. Gesture recognition like scratching the head for getting help or for showing one direction can be realized with different sensors. For input it shows, that detecting the context is of great importance in order to limit the number of options and obtain reliable results.

Figure 3: Glove with Keys [17]

For the core processing unit, i.e., the wearable computer, a means has to be found to attach it to the user hindering him/her as little as possible. In the framework of wearIT@work, the solution of a belt worn PC is followed. For the first phase, this is an Intel XScale based board design with USB, serial, Bluetooth and SD interfaces and 256 MB RAM. Batteries and interface connectors are integrated into the belt and the core unit into the buckle. This belt integrated computer named QBIC [3] has been developed by the wearIT@work project partner ETH Zürich. In this first version only Bluetooth is integrated, all further wireless and mobile communication interfaces are provided through external devices.

Figure 4: QBIC Belt Integrated Computer

IV. COMMUNICATIONS FOR WEARABLE

Considering all the application scenarios, communications from the belt worn PC (i.e., QBIC) is required to a number of different entities (persons and devices): firstly communication between other body worn devices, like sensors, the headset, head mounted display, etc. is required. This can be wired links, but preferred are wireless connections, which configure themselves automatically. Secondly communication is required between the mobile worker and the equipment and tools in the vicinity and/or in the ambient environment. Thirdly, communication between different mobile workers is required and finally also communication for information in the Internet or the company Intranet.

As it can be seen the requirements cover the complete topic of communication beyond 3G including mobility support within heterogeneous networks, Personal Area Networks (PAN), Body Area Networks (BAN) and ad hoc communications [4]. Furthermore, for the different application fields there are significant differences in the requirements regarding costs, battery lifetime, privacy and urgency of the communication. Therefore the concept defined to satisfy the requirements of the different applications but at the same time maintaining a common basis for development and implementation is to define a common interface to the service framework and the application layer (see Figure 5).

This approach has partially been followed in the SUMO project [6] by splitting hard and system dependent functions from hard and system independent functions allowing for a vertical hand over between different satellite-UMTS systems and UMTS. Another approach has also been developed in the xMOTION project [9]. Here a software module has been developed to automatically select the most suitable communication network and providing an application interface as web service. Networks considered are UMTS, GPRS and WLAN.

In wearIT@work project, a different software and system architecture is planned as shown in Figure 5 and 6. A service framework resides on top of the hardware functions.

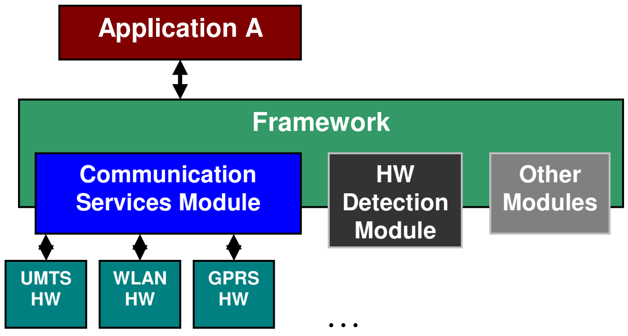

Figure 5: Software Architecture

With this architecture, applications can easily be developed and adapted to specific user requirements making use of the Framework. As, during the lifetime of the project more and further refined communication technologies and network protocols will become available, it is planned to have a communication service interface integrated in to the Framework allowing to control the communication without having to explicitly select the network, protocol or service.

This interface is provided by the **Communication Services Module** as shown in Figure 6 which consists of 4 main parts [4]:

1. **Communication Manager Component:** The Communication Manager Component is the central gateway for the framework for the lower level networking actions. It is the brain of the communication services module. Its functionality can be described as the following:
    - Automatic (re-)selection of the most suitable service and network out of available networks/services based on rules and inputs given from the framework (or user/application via framework)
    - Advice Configuration Component to configure hardware for specific services
    - Call control: Set up and close network connections
    - Configuration of the Ad hoc Networking Protocol and Mobile IP settings
    - Manage information messages from individual components and provide status information to the framework.
    - Provide defined interfaces to Framework for status and configuration. Configuration actions will provide control over communication like selecting rules for service selection and in some cases also manually selecting services.

2. **Configuration, Test and Status Component:**
This Component keeps the supported network interfaces and its initial configuration settings. It configures, sets up and clears a specific connection according to requests from the Communication Manager. It is responsible for monitoring existing network interfaces. All network interfaces have different monitoring parameters. They typically comprise availability and signal quality during inactive periods and round trip time, data rate, bit error rate during active periods. Certain values will come directly from the hardware of the mobile devices, other might not be available or accessible. Therefore additional some test features need to be implemented allowing for intrusive and non-intrusive performance measurements, like actual delay (round trip time) and throughput (data rate). All parameters to be monitored and the monitoring method (commands) are supplied by the configuration component. It should also be able to monitor other wireless infrastructures or wearable systems nearby.

3. **IP Layer:**
This layer consists of the IP implementation of the Operating System and protocol extensions like ad hoc networking and Mobile IP (MIP), partially developed by wearit@work partners. Further protocol extensions can be implemented as required in the course of the project. IP connectivity is provided to the service framework or the application itself. In the service framework further, higher level communication services can be created, e.g. http sockets with certain QoS requirements.

4. Hardware Driver Layer:

This layer comprises the hardware drivers for the different communication systems and services. Modifications might be required during the runtime of the project to better configure the communication hardware or to give access to more detailed status information.

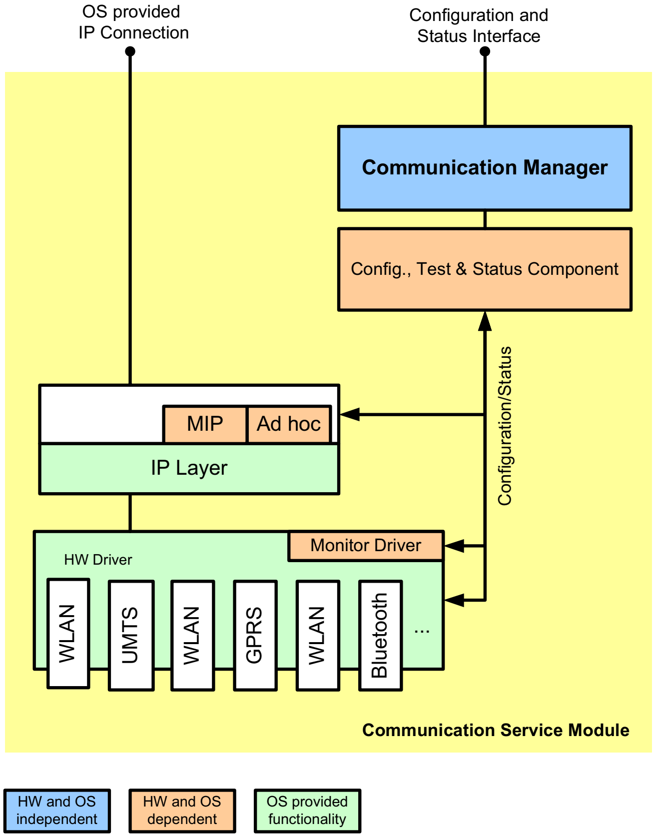

Figure 6: WearIT@Work Communication Services Module Architecture

With this software architecture all different means of communications can be provided and the different networking technologies can later be extended and improved.

The Framework (or applications/users via the Framework) can either select a rule on how to select the most appropriate network (cheapest, fastest, secured, etc.) or it can select a network out of a list of available communication networks and services provided by the Communication Service Module. The Communication Service Module can then establish the required communication, e.g. via ad hoc or infrastructure based networks. The Communication Service Module furthermore can inform the Framework and so the application or user about the available quality of service. The application can so adapt to it and e.g. store and prioritize data to be transmitted. The first version of this architecture will be available for the Mobile Summit.

With the availability of a number of interesting and suitable communication systems available, like UMTS, WLAN, Bluetooth etc. and a number of upcoming standards, like WiMax (IEEE 802.16), UWB, IEEE 802.15.4/ZigBee and having done a user requirement analysis and having taken the limited project budget for communication technology into account, the main research focus (besides of integration and development) for WearIT@work in communications has been targeted on ad hoc communications. Here existing ad hoc networking protocols are evaluated for wearable computing and protocols will be adapted for the special needs of wearable in the next years.

V. FIRST IMPLEMENTATION RESULTS

In the framework of the project, different ad hoc communication protocols have already been investigated and for the first phase different implementations of AODV [10]-[12] have been integrated and compared using different devices and operating systems. They are on Windows CE (e.g, Compaq IPAQ), Embedded Linux (e.g. Compaq IPAQ, Sharp Zaurus), Desktop Linux & Windows XP (Notebooks, PCs). Notebooks and PCs are used as Gateways to provide Internet connection to an ad hoc environment and are also used as servers (e.g, database) in the ambient environment. Later, an ad hoc protocol has to be ported to QBIC platform having a similar architecture as a Sharp Zaurus SL6000. For the review demonstration in February 2005 all above mentioned devices running different ad hoc protocols on different mobile devices have been shown in a common scenario. It consists of 2 ComPaq IPAQs, a Zaurus PDA, a QBIC and a notebook that provides the Internet gateway services to an ad hoc network via UMTS. Wireless connectivity for this demonstration is provided by IEEE 802.11b. Performance of these ad hoc implementations is analysed for the transport protocols of TCP and UDP [13]. These tests have been performed under normal environmental conditions.

A 5 nodes (4 hops) ad hoc network with AODV routing protocol [14] was used to measure UDP and TCP performance. AODV operations are enabled by UoB-JAdhoc [10] software. The packet delivery ratio is shown in Table 1, when using a UDP data rate of 500Kbps. This test ran for duration of 120 seconds while changing the number of hops between the receiver and the sender. The Packet Delivery Ratio was found to be between 99% and 100%. It was observed that most of the packet losses occurred at the beginning of the UDP transmission, immediately following the route discovery process, during the release of the buffered UDP packets. This effect encountered for the start of each route discovery process, when running AODV. In order to consume battery, processing power and utilize the wireless bandwidth efficiently, AODV keeps routes only during the data transmission.

Table 1: Packet Delivery Ratio (PDR) – (with UoB-JAdhoc)

Number of hops	2	3	4
PDR in %	99.96	99.92	99.2

To improve the throughput degradation during route breaking and establishing, UoB-JAdhoc itself performs buffering until the routes are made to the destination. Different implementations of AODV handles buffering in different manners [15]. However, applications that use transport protocols such as TCP, which have flow control mechanisms, perform better than UDP based applications, since they can adjust for link disruptions. More details of the test is available at [13].

In future, these networks have to be analysed under the specific environments as explained in the pilot scenarios (section II). Considering the firefighting scenario, performance should be analysed at least in an artificially smoked induced environment with different mobility patterns. Furthermore, protocol changes like bi-casting all messages over all available paths make sure that the increased reliability of receiving important messages by the firefighters.

The Mobile IP protocol has been modified to utilize different available networking paths (e.g. WLAN & UMTS) simultaneously. This implementation [16] has been analysed on Linux environments of Sharp Zaurus and notebooks. Deployment of Mobile IP for the wearIT@work guarantees the continuity of on going communications (e.g. video/audio conference), while a worker moves from one bearer technology to another (e.g, WLAN, UMTS to ad hoc network) and vice versa. This is mostly applicable for communications to the outside world with other persons (e.g, experts) who are on the move (roaming).

VI. SUMMARY AND OUTLOOK

In this paper an approach has been presented allowing a separation of the application development and the implementation of the communication network drivers and intelligence, which is most suitable for a design like in an Integrated Project (IP) with a large number of partners. It has been addressed that a number of suitable network protocols and communication networks and services are available to satisfy the basic requirements in wearable computing.

Nevertheless, further integration and research is required in order to improve the communication quality in the wearable computing environment focusing on the four application scenarios: firefighting, maintenance, automobile production and health care.

This means, for example in the firefighting scenario, which is most critical in the communication signal propagation environment, that multiple paths in the ad hoc networking should be followed to guarantee reachability. Furthermore issues like QoS, security, privacy need to be further researched for making ad hoc and Mobile IP protocols ideally suitable for wearable computing. For the next phase of the project the use of IPv6 is considered, as the initial show case (first phase) is based on as much as possibly existing components and therefore IPv4.

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