From BAN to AmI-BAN: micro and nano technologies in future Body Area Networks[1]

Val Jones
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Centre for Telematics and Information Technology, University of Twente
v.m.jones@utwente.nl

Abstract At the University of Twente we have been researching mobile healthcare applications since 1999. Since 2002 the University of Twente and partners have been developing health Body Area Networks (BANs) and a BAN service platform. We define a BAN as a network of communicating devices worn on, around or in the body which provides mobile services to the user. The BAN may also communicate to remote users such as healthcare providers via external network services such as GPRS or UMTS. The generic BAN has been specialised for different mhealth applications targeted at different clinical conditions to provide a variety of telemonitoring and teletreatment services. Each specialization of the BAN is equipped with a certain set of BAN devices and associated application components as appropriate to the clinical application.

Despite the considerable R&D advances made in BAN and BAN service platform development, current technology means that it is not convenient for patients to tolerate wearing current generation BANs for long periods, amongst others because they have to wear or carry and manage a collection of different devices including a PDA or smart phone. However future and emerging technologies such as Ambient Intelligent Environments enabled by nano-technologies open the way for less obtrusive and more transparent systems and services. We envision increasing miniaturization enabling the "disappearing BAN" or AmI-BAN, incorporating micro- and nano-scale devices, processes and materials, possibly implanted, communicating with the Ambient Intelligent Environment to provide cost-effective, unobtrusive, pervasive, context aware services (eg. detection, diagnosis, monitoring, treatment). Examples of some possible future AmI-BAN applications using micro-, bio- and and nano-technologies are presented.

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Introduction

The CTIT mhealth team at the University of Twente have been researching mobile healthcare applications (Jones et al, 1999; Jones, 2001) and Body Area Networks for trauma care and homecare (Jones et al, 2001) since 2001. Since 2002 we have been developing health Body Area Networks (BANs) (Konstantas et al, 2002) and a BAN service platform (van Halteren et al, 2003; Dokovsky et al, 2003). The first prototype was funded under the IST FP6 project MobiHealth (2002-2004), and development continues under the Dutch FREEBAND project AWARENESS and the European eTEN project HealthService24. In Mobihealth we combined the ideas of Body Area Networks (BANs), wireless communications and wearable devices (sensors, actuators...) to provide m-health services for patients and health professionals. The BAN service platform and a number of variants of the health BAN were trialled in 4 European countries, with various biosignals monitored and transmitted to remote healthcare locations over GPRS and UMTS. The nine clinical trials in MobiHealth included telemonitoring for cardiology and respiratory insufficiency (COPD) patients, for pregnant mothers and in trauma care.

We define the generic BAN architecture as a network of devices, with an MBU (Mobile Base Unit) connected (by wireless or wired IntraBAN links) to a set of BAN connected devices. Sensors and actuators are examples of BAN connected devices. The MBU handles processing and is the gateway for Intra-BAN and ExtraBAN communication. Figure 1 shows one BAN configuration (for COPD patients). Here the MBU is implemented on a PDA (a Qtek) and this BAN is equipped with a respiration sensor and 3-channel ECG. Figure 2 shows the generic architecture of the MobiHealth BAN.

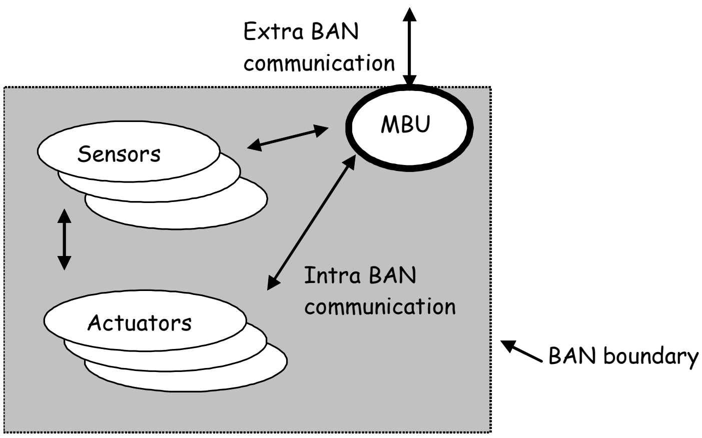

Figure 1. COPD BAN

Figure 2. Generic BAN architecture

In the Awareness project development of the BAN and BAN service platform continues, with the main focus however on development of *context aware* BAN-based m-health applications. The clinical applications currently being developed in Awareness are tele-monitoring (to detect epileptic seizures, and uncontrolled movements in spasticity for spinal cord lesion patients) and tele-treatment (for management of chronic pain).

The eTEN HealthService24 project also conducts further BAN development together with further development of the cardiology, COPD and pregnancy monitoring services. In preparation for commercialisation, HealthService24 focuses on the business context of mhealth service provision.

Over the course of these projects a range of BAN sensors have been deployed including: electrodes (for measurement of ECG and EMG), pulse oxymeter (to measure pulse plethysmogram and oxygen saturation), also respiration, temperature and activity (step-counter) sensors. Currently there are 35 BANs operational in 4 EU countries; the status of the system is a research system for use in medical trials (non-certified).

The development team have made enormous progress in BAN and BAN service platform development, however current generation BANs have not yet reached desirable levels of unobtrusiveness and user friendliness, due to various limitations of current technologies. We envisage several directions in which BANs may evolve in the long term to overcome some of these shortcomings; in this paper we examine how future and emerging bio- micro- and nanotechnologies may enable health BANs of the future. Specifically three directions of possible future evolution are enabled by:

- *Wearable microelectronics*
- *Implanted micro devices*
- *bio-nanotechnology*

Wearable microelectronics

With this direction of development we consider the components of the BAN (devices and communications channels) integrated into clothing or 'body furniture. Much work has been done by the research community on development of smart textiles and integration of microelectronics into clothing, jewelry, spectacles and so forth. At Twente the BAN development team have experimented with incorporating the MBU into the Qbic belt computer. In the European MOSAIC project and the under the Ami@Work initiative researchers at Twente also developed a future vision of BANs evolving into AMI-suits for emergency services personnel in the context of major incident management (Jones & Saranummi, 2005). For example police uniforms would incorporate vital signs, audio-visual communications and positioning functionality in the textiles. In addition to these functions, firefighters' suits would also incorporate environmental sensors to measure parameters such as external temperature, carbon monoxide and carbon dioxide levels. Paramedics' uniforms would also be able to discover and query patient BANs and link BAN data with the electronic medical record. Audio-visual communications integrated into the paramedic uniforms would enable telepresence and augmented reality experience of the scene for hospital staff. Similarly disaster coordinators could benefit from remote viewing of the scene using the same technology (see Figure 3).

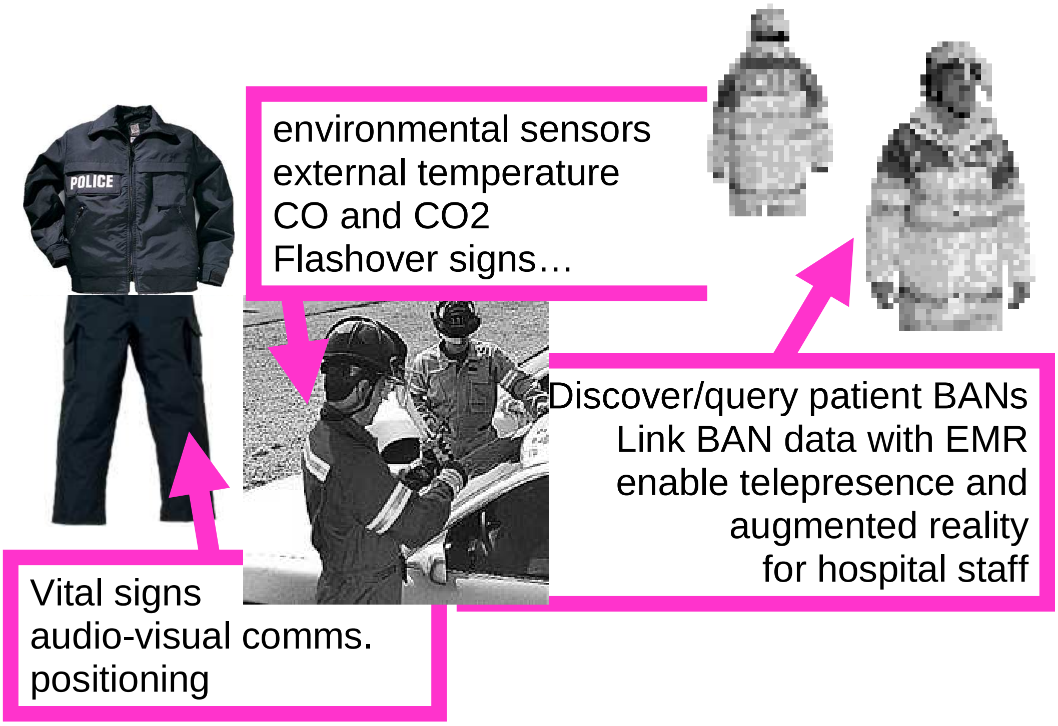

Fig. 3 AmIBAN integrated into emergency workers' uniforms

Implanted micro devices

Medical implants (eg. pacemakers, prostheses, stents) have long been in routine use. With increased miniaturization many micro implants are being developed and some are already in use. One example is a sensor targeted at Congestive Heart Failure patients. The implanted sensor is "the size of a grain of rice" and can be used to measure pressure, flow, temperature or irradiation dosage. The device can also be used an activator for drug therapies or nerve or tissue stimulation. Acoustic waves are used for through-body communications and to energize the implant http://www.remonmedical.com/. Another example is an implanted neurostimulator for treatment of epilepsy, spasticity and movement disorders, chronic pain, profound hearing loss, incontinence or certain kinds of depression http://www.future-fab.com/documents.asp?d_ID=3725.

For health BANs, the development of *micro* implants opens up the possibility of Intra Body Networks (IBNs), where BAN components are miniaturised and disappear inside the body. Not only sensors and actuators, but one day perhaps also MBU functionality (computation, storage, communication) can be realised by implanted devices communicating wirelessly through tissue. Our generic BAN architecture should encompass this possibility, enabling integration of micro implants into the BAN to create Intra-Body Networks. We have already discussed with clinical partners the possibility of using implanted sensors to give engineering feedback on performance of prostheses (eg. recording and transmitting real-time engineering data such as stresses and loads on artificial joints). Furthermore sensor–actuator coupling gives the possibility of utilizing close coupled feedback control loops. Some possible applications are: activation of implanted defibrillators for cardiac arrhythmia patients (eg. in long QT syndrome). Such devices are already in routine clinical use as standalone systems but could be components of a BAN or IBN. IBNs could also be used to tune power output of pacemakers after surgical implantation and for control of implanted medication pumps.

Bio-nanotechnology

Much further into the future we can anticipate BANs and IBNs which make use of various bio-nanotechnologies. One definition of Biotechnology is "Any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use" www.wfed.org/resources/glossary/ . The UK Institute of Nanotechnology define nanotechnology as "science and technology where dimensions and tolerances in the range of 0.1 - 100 nm play a critical role"[2]. Richard Feynman is credited with inventing the concept of nanotechnology in 1959, with the more specific concept of *molecular machines* (aka. molecular nanotechnology or molecular manufacturing). His concept was of a branch of engineering which deals with the design and manufacture of extremely small electronic circuits and mechanical devices at the molecular level of matter. Bio-nanotechnology can be defined as "a branch of nanotechnology based on using the biological structures such as proteins, ATP's, DNA, etc. as building blocks of nanoscale devices (e.g. nanomotors)" http://nanoatlas.ifs.hr/bio-nanotechnology.html. Bio-nanotechnology may combine biological ("wet") components with engineered, synthetic ("dry") components, and hence is also known as 'wet-dry' technology. By utilising or mimicking biological processes, bio-nanotechnology is, amongst other things, exploring how to replicate the fundamental operations of signal processing and signal transmission, computation and communication (which already occur in living systems) by manipulating bio-mechanisms at cellular and molecular scale.

Molecular computing and molecular communications

Molecular communications represent a convergence of nano- bio- and communications technology by allowing biological and artificial components to communicate. The sender encodes information onto a molecule, which is propagated to a receiver who decodes information and acts on it. Moore et al (2006) discuss basic building blocks of computation and communication including molecular logic gates (eg. inverters and NAND gates), signal processing and transmission mechanisms, information encoding/decoding mechanisms, memory, mechanisms for routing, addressing and relaying, both for single and multi hop communications. Moritani et al (2006) describe a communications mechanism where a microbead acts as an information molecule and is loaded onto a transporter molecule (a microtubule) which glides along a microlithographic track powered by biomolecular linear motor made of immobilised

[2] 1 nanometer = 10-9 m, or one billionth of a meter.

motor proteins. They propose DNA hybridisation as a means to load and unload information.

Molecular devices

Work is ongoing on nano-sensors; for instance Sasaki et al (2006) propose construction of a sensory device for selective detection of ‘biologically important molecules’ using amines as input signals, synthetic receptors, the enzyme LDH and a copper ion as mediator, the whole mounted on an (artificial) liposome cell membrane to provide a platform for integration of nano-components and communication between them. Moritani et al (2006) describe nano-scale actuators/effectors where a receiver reacts to a decoded signal, for example a captured molecule is introduced into a cell and produces biochemical reaction. The reaction may be to deliver drug or DNA to a targeted cell, to trigger altered morphology or cell movement or even gene expression.

These three research groups see future applications in biomedicine and healthcare including nano-devices for metabolism control, energy conversion and information processing (Sasaki et al, 2006), Lab-on-a-chip (eg. for cell analysis or blood diagnosis) and implanted drug/DNA delivery systems (Moritani et al, 2006). For the latter they propose hormones as carrier molecules, delivered via endocrine pathways. One big advantage here and in general is that bio-nanotechnologies offer the promise of bio-friendly intervention. Moritani et al (2006) also envisage human body monitoring using implanted biochemical sensors to detect specific molecules (eg. allergens or viruses) and to perform functions such as physical check-ups and artificial control of immunoreactions.

In Conclusion

We see that the major functions of health BANs: sensing, actuating, signal processing, computation, information processing and communication are being researched or developed at nano-scale (albeit sometimes in very early stages of research). Nevertheless, this opens up the future possibility of the nanoBAN consisting partly or entirely of communicating implants and able to provide many kinds of monitoring, diagnostic, analytic and therapeutic services. Not only *in vivo* applications may be involved, also we can anticipate in the nearer future that *in vitro* micro and nanoscale devices (eg. Lab-on-a-chip for home use) may be integrated into, or communicate wirelessly with, current generation health BANs. We can adopt this very futuristic concept as one of the long term visions driving our health BAN research.

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