System Architecture for Mobile-phone-readable RF Memory Tags

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***Abstract*—This study is about developing an open architecture platform for implementing passive RFID tags with a mass memory. Purposes for such mass memory tags are, e.g., multimedia files embedded in advertisements or logged sensor data on a low-power sensor node. In the proposed architecture, a mobile phone acts as the reader that can read or write the memory of these RFID tags. The reading speed, demonstrated to be in excess of 50Mb/s is in range that a 3-minute VGA size video can be loaded from the tag to the phone in less than 10s. The architecture is designed so that development path to a full Network on Terminal Architecture (NoTA) compatibility is feasible.**

Keywords: Memory architecture, Multimedia systems, RFID, telephone sets

I. Introduction

RFID tags are increasingly a part of our life; transport, traceability, and secure access are some of the main uses of this technology today. Conventional machine-readable wireless tags, e.g. Near Field Communication (NFC) tags, normally have a very small memory in range of hundreds of bytes or kilobytes [1]. For instance, the popular MIFARE 1k tag has one kilobyte of memory from which the user can utilize 768 bytes [2]. With 1 or 2-dimensional optical tags (barcodes) memory limitations are even more severe. Thus, they are basically only machine-readable identification codes. Some RFID standards include an option to have a flexible-use memory, but the capacity is low compared to factory-set fixed-content memory. Tag selection is based on reading the content in a selected tag memory address (e.g. tag or manufacturer ID). The reader must know the tag memory structure – thus it has to be pre-defined for an application. As the memory capacity of these tags is small, the amount of data to be transferred is also small and power consumption of RF communication is, thus, not a critical issue.

To get over the problem of limited amount of information that can be stored on a passive tag, Wu et al. increase effective tag storage sizes with proposed distributed RFID tag storage infrastructure (D-RFID stores) [3]. Tags would be distributed in space and time in this architecture. Ahmed et al. focus on RFID system unreliability and improvements in middleware for object tracking and object location with moving readers or tags [4][5]. As a result of their research, a virtual reader system architecture was introduced. Ying described a verification platform for RFID reader that utilized UHF frequency [6]. This platform is applicable for customization with different RFID standards.

In this paper we describe and demonstrate a network architecture at which a mobile phone acts as the trusted intelligent user interface for reading and writing passive RFID (Radio Frequency Identification) tags that contain a mass memory. This architecture has been developed in the EU 6th framework integrated project MINAmI and according to project name it is referred to as the MINAmI architecture [7].

The aim of our research has been to develop a mobile-phone-operable memory tag suitable for consumer markets and ubimedia applications [8]. We emphasize that MINAmI Memory Tag (i.e. mobile reader/writer and tag) solution, is currently under test and integration phase in the MINAmI project. The preliminary technical results are promising and useful for the concept of mobile-phone-readable mass memory tags. This high speed (50Mbit/s) has been achieved in the technical demonstrations. This shows that mobile reader/writer and the high capacity memory tag is implementable.

Our vision refers to a surrounding ambient intelligence system with which a user can interact through his/her personal mobile terminal. Following this vision, a mobile-phone-based system architecture is proposed, including a personal mobile terminal with access to wireless sensors and memory tags in near proximity, and Internet connectivity.

Compared to other candidates for a portable user interface device, such as personal digital assistants (PDA) or laptop computers, mobile phones have several advantages: highest market penetration and acceptance amongst users, relatively low cost and small size, both local and long-range wireless connectivity, access to a wide range of services via the Internet, data storage, local computational capacity, and a user interface that can be – to an extent – defined by software. For instance, today's mobile phones provide music and video players, which make it possible for consumers to enjoy entertainment while on the move. Acquiring new multimedia content by downloading or streaming, however, is hampered by the high cost and slow speed of Internet connections, as well as by the fact that commonly used physical multimedia formats, such as optical disks, cannot be read with a mobile phone. To make acquiring new content easier, cheaper and less power-consuming, we propose a new technology based on RFID memory tags readable and writable by mobile phones.

The attention span of a mobile user is about 10 seconds [9]. Within this period, the user could get a single multimedia content file from a memory tag (taking into account simple communication channel establishment and protocol overhead). Considering a movie trailer, the file size for a 2-minute 640x320-pixel 30-fps (3Mb/s), encoded with H.264, would be in range of 50MB [10]. The required minimum data transfer rate from the user point-of-view thus is 50Mbit/s. This exceeds the maximum data rate available by 13.56MHz NFC technology, 848kbit/s, by a factor of 60. Even the maximum data rate for NFC demonstrated on a laboratory set-up, 6.78Mbit/s [11], is not enough. Thus, there is a need for a new high-speed touch-range RFID radio interface.

The reasoning for the proposed technology was also justified by modern trends in the field of non-volatile memory technologies according to which the power consumption, physical size and price of (non-volatile) memories are continuously decreasing. This enables development of RFID memory tags which can be accessed wirelessly with mobile phones to support a multitude of applications and usage environments [12].

Important architecture requirements include openness, modularity, scalability and energy efficiency. Openness and modularity are needed to support creation of novel ambient intelligence applications and services by different industry players. Scalability of data transfer rate is needed to enable evolution of the technology along with evolution of multimedia services.

The paper is organized as follows. In Chapter II, we introduce the system architecture, along with a key component of the architecture, RF memory tags. In Chapter III we introduce a novel dual-band radio subsystem and its hardware and software implementation. In Chapter IV, we present the current status of implementation of the architecture, and in Chapter V we discuss possibilities for future development.

II. MINAMI ARCHITECTURE

The proposed MINAmI architecture makes use of the mobile phone's capability of running software and providing several radio interfaces (Fig. 1 [8]). The architecture development has clearly benefited from the requirement of modularity, which enables simpler and faster development of new technical extensions (e.g. for memory tags). Modularity also allows faster prototyping of possible new use cases (e.g. reading memory tags with a mobile phone). Our architecture focuses on utilization of modularity on component level (e.g. where to plug memory tag functionality) and on communication level (e.g. how mobile-phone-centric architecture is able to utilize the available memory tags). At short proximity domain (range<1m), different tags are

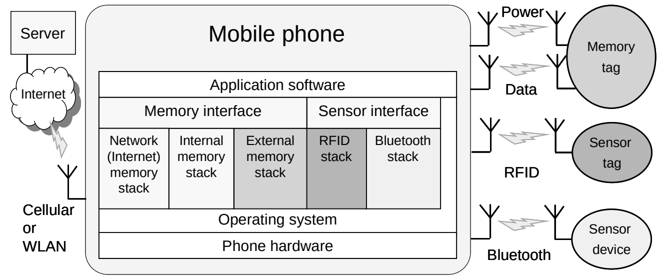

Figure 1. MINAmI Architecture. The Bluetooth stack includes both Classic Bluetooth and Bluetooth Low Energy profiles. On a sensor device side only either Classic BT or BT Low Energy stack is needed.

communicating locally with a mobile phone. Memory tags provide wireless storage capacity and an internal memory interface and sensor tags provide sensing data and an internal sensor interface. In this paper we will concentrate on the memory tags. The sensor parts of the architecture (RFID sensor tags and Bluetooth sensor devices) have been studied in an earlier project (see [13] and [14]).

A. *Mass Memory Tags*

The focus of our research has been on mobile-phone-operable memory tags suitable for consumer markets and ubimedia applications. The tag is developed as a part of a mobile-phone-centric architecture shown in Fig. 1. Our memory tag development targets improving both transfer speed and storage capacity. These improvements give direct benefit for ubimedia users. Transactions happen faster and more efficiently compared to current NFC tags. Also response times experienced by the user are within an acceptable range, even when moving tens of megabytes of data.

The target memory capacity of our memory tag has been in the range of gigabits and mobile reader/writer transfer speed to and from memory tag in excess of 10Mbit/s. The same design platform is usable for both ends, for mobile phone platform reader/writer and for memory tag implementation. When designing the platform, various important design parameters, such as the selection of the used radio technology, were considered carefully to provide an efficient and low-power solution for mobile reader/writer and tags.

It was important to make sure that connectivity technology is simple enough for the user, e.g., to facilitate easy content selection (see Section III.D). Memory tag content selections should be based on metadata (e.g., filenames, file content types, file content keywords). Due to the large memory size, power consumption for memory access is a critical design issue, both for reading and writing the memory tag. The memory tag technology described in this paper is capable to meet these technical requirements.

To be successful on the market, RF memory tags for ubimedia should be passive to make them as small (in size) and cheap as possible. This severely limits the power available on the tags for communications and memory access. On the other hand, a short communication range (even touch) is preferable to make it easier for the user to physically select the tag he or she wants. An RF memory tag could be read very many times by different users, but written not so often – in some cases, only once. The memory unit must work reliably even with several consecutive read cycles. A limited write throughput due to power constraint seems not to be an issue, as data is rarely written by the users.

Traditionally available high capacity low-power non-volatile memories (NVM), such as NAND flash memory, are poorly usable in passive memory tags due to big energy consumption of the system especially when writing. This is because NAND needs much higher programming voltage, 20V, compared to the 3V programming voltage required by phase-change memory (PCM) [15]. The development of novel NVM like PCM has made it possible to develop a passive memory tag that would, in contrast to the conventional RFID tags, provides memory capacities comparable to popular Universal Serial Bus (USB) memory sticks as well as a file system with metadata.

B. Network-on-Terminal Architecture (NoTA)

Network on Terminal Architecture (NoTA) is a modular service-based system architecture for mobile and embedded devices offering services and applications to each other. These devices are built on bigger functional modules in a distributed manner, called Service (SN) and Application (AN) Nodes. Such functional modules can be common for system (e.g. keyboard, storage, and network service modules) or more specialized to certain function (e.g. memory tag, sensor device modules). By combining a set of application and/or service nodes, a more specialized functional unit can be constructed, called a subsystem (Fig. 2).

The concept is being defined in open initiative, in NoTA World [16]. NoTA is also known as an open device distributed architecture, which allows direct connections between different nodes, within subsystem or between subsystems. This architecture supports both messaging and streaming type content transfer, i.e. “services”. If a subsystem needs functions not internally available, it can request services from other subsystems. One subsystem is aware of the other available subsystems that offer services (or applications). This subsystem may also be offering services to other subsystems, and utilizing other services from another subsystem (Service Node). For example Application Nodes (AN) use available services (printing, storing, reading/writing, networking etc.) The beauty in the architecture resides in modularity and transport independency. Transport-specific portion is hidden underneath NoTA communication layering.

NoTA communication layering is built around different transport-independent parts, and interfacing towards transport-specific parts (Fig. 3). Device Interconnect Protocol (DIP) provides logical link between requesting subsystem and other subsystem or within one subsystem. DIP protocol specifies two communication layers, High Interconnect (H_IN) and Low Interconnect (L_IN). High Interconnect specifies service discovery, service activation and deactivation as well as service and stream access. Low Interconnect specifies connections; both transport independent and dependent parts, where multiple of transport dependent parts can be used by one transport independent part [17]. We note that DIP is a device level communication protocol that can be implemented for various physical interfaces ranging from MIPI (Mobile Industry Processor Interface) high speed serial interfaces and USB to wireless interfaces like Bluetooth [18][19].

MINAmI architecture of Fig. 1 will evolve towards a

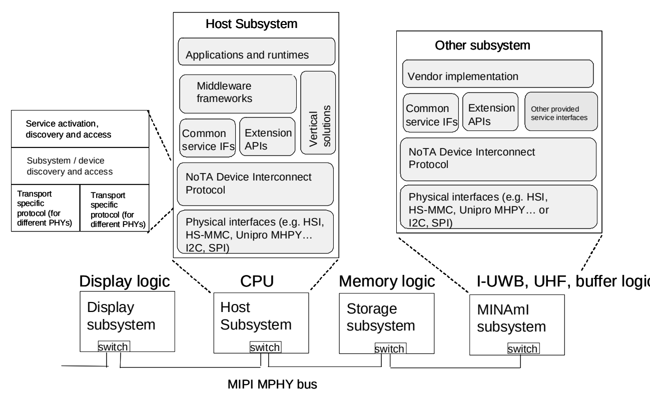

Figure 3. MINAmI subsystem NoTA extension architecture

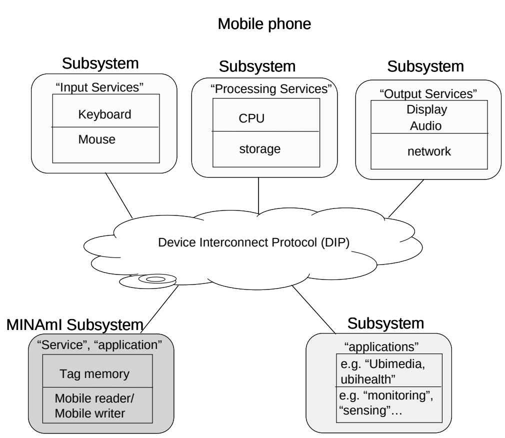

Figure 2. Functional and modular NoTA architecture

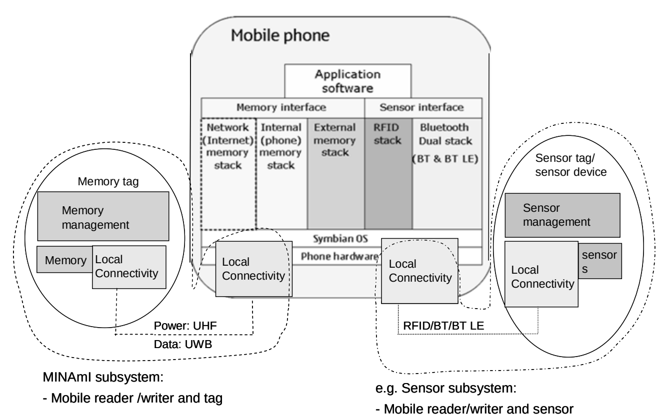

Figure 4. MINAmI architecture and MINAmI subsystem evolving towards NoTA compatibility.

NoTA-compatible architecture. There are commonalities in the architectural structure, as subsystems can easily be identified in both sides (e.g. MINAmI subsystem provides memory tag read/write service). By dividing the MINAmI architecture according to Fig. 4 (two different dotted lines), two or more subsystems can be found, the actual MINAmI subsystem and a sensor subsystem.

MINAmI subsystem includes both mobile phone (Mobile Reader/Writer) and the tag and all the hardware and software resources needed to build it. MINAmI subsystem offers reading and writing, storage, and local connectivity service from the tag to other subsystems and the host. Mobile Reader/Writer sees the contents of the memory of a passive RF memory tag, only when there is an established connection.

NoTA host subsystem and neighboring subsystems are connected together via an available high speed physical interface (Fig. 3). Device Interconnect Protocol adapts physical interfaces to the upper layers. It is the lowest layer that is common for all subsystems and that hides the physical dependencies underneath. Above DIP there is a common service interface used for resource management, file systems, and system boot-ups. Middleware frameworks, e.g. for multimedia, USB, and other applications, use a common service interface or extension API. The architecture takes into account also vertical solutions, which may require an optimized protocol design for certain requirements that are tied to HW-specific applications.

Each subsystem is either able to select the data or switch the data through. For example, the memory subsystem can directly communicate with the display subsystem through this high-speed physical bus.

III. UWB Low End Extension

As memory tags have high data storage capacity, a high-speed radio is needed for communication to make possible reading even all the contents of the tag in an acceptable time. Currently available mobile phones contain several radio transmitters, such as UMTS/HSDPA and GSM/GPRS (cellular), Bluetooth, and WLAN (IEEE 802.11), along with NFC. Most of these technologies are made for well-established communication between active devices, consuming a relatively large amount of power, out of the reach for wireless powering. These technologies are also not inherently designed for ad-hoc, possibly one-time, connection between devices that have not communicated with each other before, resulting in long latency in establishing the communications. For example, in an environment with many unknown Bluetooth devices, the Bluetooth connection setup latency can be over 10 seconds [20]. NFC enables communications between an active and a passive battery-less device and is physically more selective, as its communications range is almost touch. However, it has severe limitations in data transfer speed, as mentioned above, and therefore it's not suitable for RF memory tag applications, at least without significant enhancements.

To provide higher data rates, a wider frequency band available on higher frequencies needs to be used. On the other hand, the efficiency of wireless power transfer (WPT) decreases as a function of center frequency. To solve the problem of providing high-speed communication (high frequency needed) while simultaneously providing power wirelessly to the tag, a dual-band radio interface has been proposed [21]. One narrowband signal on RFID frequencies (e.g. on 13.56MHz NFC band or on UHF RFID frequency bands globally available between 860–960MHz) is used to power the tag and synchronize the communication link, whereas the communication link itself is based on impulse UWB technique to provide high communication bandwidth and scalability for even higher data rates.

As the UHF RFID frequencies are approximately in the same frequency range as GSM/WCDMA 900MHz, in the reader there is a possibility of integrating the WPT function to the existing Phone Radio Subsystem, as presented in Fig. 5. In that case, the Phone Radio Subsystem should be designed so that WPT PHY function may request a direct access to control the activation of the 900MHz narrowband transmitter. Especially, the time-domain interleaving of different functions is important to support co-existence of GSM/WCDMA and WPT signaling. If NFC is used as the WPT, similar cooperation with the NFC Subsystem must be

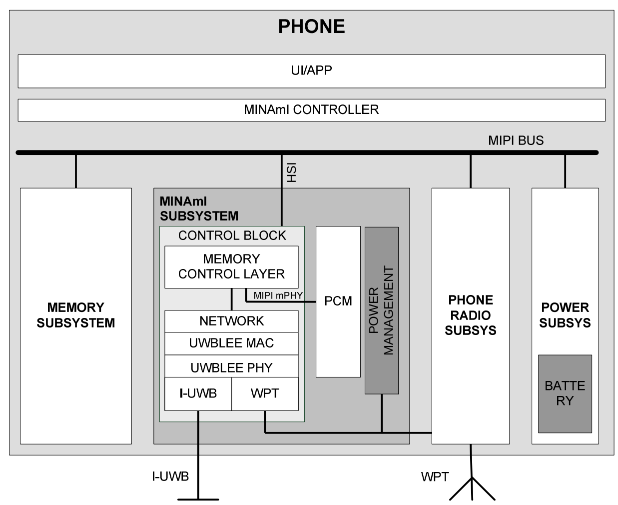

Figure 5. MINAmI architecture on a phone

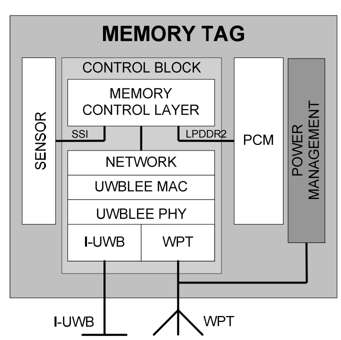

Figure 6. MINAmI architecture on a RF memory tag

specified.

The architecture of a RF memory tag (Fig. 6) is similar to the MINAmI subsystem on the mobile phone. For simple RF memory tags, only a simple network layer implementation is needed to take care of direct communication between the reader and the tag.

As an option for use-cases like data-logging sensor devices, the memory control layer can provide a sensor interface. During the sensing, the sensor data is stored to the PCM block. When a reader device powers the sensor tag, all or parts of sensor data can be streamed to the reader through the UWBLEE radio.

A. Hardware architecture

1) Radio front-end

As presented in [21], a very simple super-regenerative transceiver architecture can be used in impulse UWB communication to achieve required data-rates (>50Mbit/s) over short distances sufficient for RF memory tag applications. In contrast to conventional impulse UWB transceivers [22] used, for example, in sensor networks, there is basically no need for multipath recovery over the distances in the range of several tens of centimeters (maximum distance 20–30cm). This essentially decreases the performance requirements set for the impulse UWB transceivers in this context. In the aforementioned super-regenerative transceiver one super-regenerative oscillator is used alternately both to generate transmitted pulses and to amplify received pulses, and no linear amplifiers are needed. Thus, the architecture takes benefit from the inherently low duty cycle of transmitted impulse UWB signal also in reception since the receiver is fully active only exactly during the detection of incoming pulses. Altogether, the optimized transceiver architecture makes it possible to achieve power consumption performance (in range of several milliwatts) suitable for WPT. Due to the simplified transceiver structure, targeted ultra-low power consumption and partial exploitation (500MHz) of full UWB band (3.1–10.6GHz) authorized by FCC regulations for unlicensed use, the impulse UWB system referred here is called UWBLEE (UWB Low End Extension).

Synchronization is often problematic in impulse UWB systems because of the low duty cycle and pseudo-random timing of pulsed signal and due to frequency differences of reference clocks in different transceivers. If the duty cycle of the receiver is also low, preamble patterns used for synchronization must be repeated multiple times to ensure high probability of correct reception. In the proposed system the frequency synchronization between the reader and tag is achieved thanks to the mutual narrowband WPT signal which can be also used as reference clock for the communication. The phase synchronization of impulse UWB transceivers is also easier to achieve due to decreased need for pseudo-random time-coding of pulse patterns. The development of optimized PHY protocols for the system is under way.

The aforementioned transceiver structure naturally supports simple On-Off-Keying (OOK) modulation and due to energy-based detection, complex modulation methods are impractical to use. As mentioned, due to the high SNR over the short distances the coding of data for example with one pulse per bit is feasible to maximize the data-rate over the air. For the air-interface the data from/to non-volatile storage memory (PCM) is buffered into a DPRAM buffer memory equal to the size of packets transferred over the air.

2) Non-Volatile Memory (NVM) technology

As it was highlighted above, the most suitable non-volatile memory candidate technology for RF memory tags was identified as PCM (phase-change memory). The main reason to pick up PCM in favor of any other memory technology [23] were the benefits of PCM technology, e.g., the estimated high number of read/write cycles as 1x10^6 which consequently results in need of no or just a lightweight wear leveling algorithm, and bit alterability – lack of need of block erase cycles (as with flash memory) when data should be stored.

From the perspective of technology lifecycle PCM stands now between pure innovative technology and early adopters' stage. There are several 90nm products [24] on the market already and more to come.

Aggregating main memory characteristics in comparison with NAND/NOR flash technology and DRAM execution memory, PCM stands between those two in terms of cost per die. It is characterized as 5.5F^2 factor in cell size having the same wafer complexity as DRAM technology.

Currently only Single Level Cell (SLC) PCM is available, though Multi-Level Cell (MLC) PCM is on the way out which can substantially extend the density and, justify the cost structure. Thus, the application range can be quite wide from external usage (cards, keys) and wireless applications (RF memory tags) to high performance computing applications (caches, code execution, data storage). Considering reliability characteristics it is important to note that PCM technology gives more than 10 years retention ratio that can be extended even further, if necessary, by proper bit error management.

PCM has performance characteristics such as read & write latency and read & write endurance almost as good as DRAM, while giving clear benefits through the non-volatile nature of PCM technology. PCM has a low system-wise energy consumption (~0.2mW/pF read, <1.25mW write) ~<1mW/GB of idle power, access time comparable to DRAM (~85ns), with read latency 50–100ns, write bandwidth from 10 to 100+ MB/s/die, write latency 500ns–1µs, various packaging/die stacking solutions, high-speed low-pin-count low-power interface solutions, and maturity of the technology as such.

Above-mentioned PCM technology highlights provide clear reasoning behind the selection of such technology for the RF memory tag application, preserving the opportunity to justify it even further when some other application should be designed.

B. *Software architecture (protocol stack)*

The MINAmI software architecture (protocol stack) is designed to be modular and freely scalable. The protocol stack is based on three layers: Network Layer, Medium Access Control (MAC) Layer, and Physical (PHY) Layer. The application programming interfaces (API) of the layers are open for 3rd parties. These layers will be presented in the following sections.

The protocol stack has been developed taking into mind future compatibility with NoTA architecture. There may be an intermediate step, but care should be taken to have clear implementation path towards the final architecture (NoTA) solution.

1) *Network layer*

Network Layer will first only provide point-to-point connections regardless of state. In future, also applications using multiple targets could become feasible when MINAmI Subsystem is in active mode.

For an intermediate solution, point-to-point network protocol is used, or a point-to-multipoint protocol is used from the start. Easily implementable could be the UART and nanoIP protocols used in MIMOSA [13]. If a networking protocol is used, there is a choice between nanoTCP and nanoUDP types of messaging, i.e. TCP-type messaging should be used if traffic control, proof of message receives and retransmission is needed. NanoIP is free and open source [25]. If compared to full IP protocol, NanoIP includes less overhead for these embedded subnets. But to get full internet support classical IP protocol may be valid, and more common in networking devices.

In the final architecture (NoTA) solution, the network layer will consist of Device Interconnect Protocol (DIP), as a middleware, which guarantees the compatibility with NoTA. In DIP protocol, there is possible to setup which transport and network to be used. For example DIP TCP L_IN (transport selected) is ready to use within one device and between several devices within the sub-network without any special configuration. Multicasting must be enabled in IP interface in order for device discovery to work. Nodes, which are in different sub-network, cannot be detected [26].

Packet size is an issue and depends on what is feasible or optimal for MAC/PHY layers. Upper layer packets are segmented and reassembled and this is dependent on what kind of packets size the system supports.

2) *MAC layer*

The medium access control (MAC) of the novel dual-channel RFID interface has three different operational modes: passive mode, where no internal power source is available or used; and active mode and semi-passive mode, where internal power source is available and in use. Tags on battery-less objects without power wire connection (e.g., implanted on paper) are passive.

In active mode, the mobile phone actively searches and selects the target tags, sends the targets the Wireless Power Transfer (WPT) signal for powering and synchronizing the connection, reads/writes data on the tags, and closes the connection to the target when active connection is no longer required. This operation can be an automatic feature, or enabled by the user (initiating the application for reading and writing the tag). In semi-passive mode the phone receives data sent by an outside device, but powers itself, making possible longer communications range otherwise often limited by the WPT link. In semi-passive mode, however, the outside device takes care of synchronizing the I-UWB communications.

Active mode states are used by battery-powered mobile devices, whereas passive mode states are applied for passive devices and tags. In passive mode, possible connections are powered by an outside device with WPT. Passive mode may be in a certain default state when powered by an outside device (in P-IDLE, e.g. ready to receive any data).

Main operational states of UWBLEE MAC are shown in Fig. 7 and Fig. 8. In addition to the shown directions of movement from state to state, there need to be possibility of built-in error recovery operation from any operational state to the corresponding idle state (A-IDLE or P-IDLE). For some cases security may be applied to ongoing data transmission (e.g. NFC-like security).

3) *Physical layer*

UWBLEE PHY (physical layer) should both control the I-UWB communications and Wireless Power Transfer (WPT) transmission. Depending on the operational mode

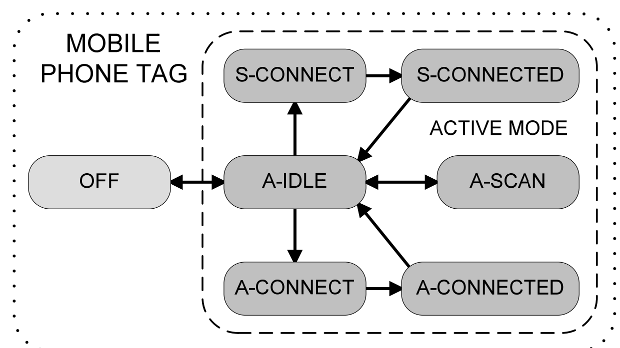

Figure 7. Active (and semi-passive) UWBLEE MAC states on a mobile phone. Active states denoted with A, semi-passive with S.

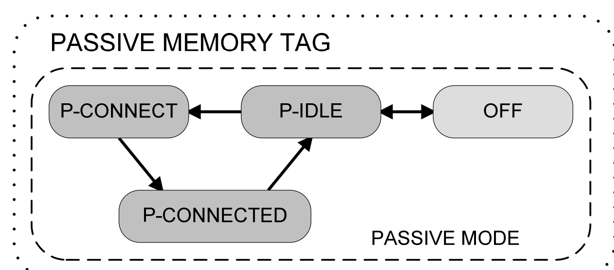

Figure 8. Passive UWBLEE MAC states on a RF memory tag.

(active or passive) WPT link is used to send (or receive) power and/or to provide a synchronizing signal through, e.g., NFC or EPC antenna.

UWBLEE PHY is divided to two sub-blocks: I-UWB PHY and WPT PHY. I-UWB PHY controls the Impulse-UWB radio interface and WPT PHY controls the Wireless Power Transfer interface. I-UWB PHY and WPT PHY must be coordinated by UWBLEE PHY so that I-UWB transmission is synchronized with the WPT transmission.

The function performed by UWBLEE PHY is defined by UWBLEE MAC, as shown in Table I.

C. Packet-level communication

The MINAmI subsystem communication between active mobile reader/writer and passive RF memory tag consists of periods shown in Fig. 9. In start position there are no tags within the MINAmI subsystem (i.e. mobile reader/writer) local connectivity coverage. If the mobile reader/writer detects a tag during the powering period, it tries to scan all tags available (in the polling period) and – based on the current selection criteria – choose one with whom to communicate (in the activation period). The right tag is found by scanning the coverage area, synchronizing communications with the tags, and selecting the right tag. After this selection, connection and device configuration is executed in the initialization period to set communication parameters, to specify packet level parameters (e.g., length, memory allocation). The connection period is initiated when connection between mobile reader/writer and selected tag is established. This is followed by the data transmission period, reading and/or writing selected content from / to tag. After successful data transmissions, in the termination period, connection can be closed or continued with another read/write operation to the tag.

Basic connection procedure between a mobile reader and a tag is described in Fig. 10. The figure also identifies affected internal entities, main entities being MINAmI server, memory management, and communication entity (MAC, Medium Access Control, and PHY, Physical layers).

D. File system design

The mobile phone can read tags and with writeable tags the phone can also write all or parts of their contents. The communication capacity between the mobile terminal and the mass memory tag is targeted to exceed 50Mb/s – in contrast to, e.g. NFC, which provides speeds up to 848kb/s. Within a single reading period, the user could download a multimedia file – about 50MB in size – from the memory tag (taking into account simple communication channel establishment and protocol overhead). We need to develop plug-in software (External memory stack in Fig. 1) to facilitate seamless use of the tag memory for mobile phone applications.

The memory tag can be used as an extension to the local file system of the reader (e.g., mobile phone). The memory tag can be either a passive and cheap one (Fig. 11) or an active one, including an own power source and thus being more expensive (Fig. 12) [27]. Plug-in software in the file system of the reading device handles the connection to the memory tag. Storage space on the memory is mounted on the local file system in the same way as any detachable storage. The volatile nature of the connection causes overhead in maintaining the file system view.

Adding a processing element to the memory simplifies the connection. The processing element can also be externally powered, so even this kind of a memory tag can be passive. An active memory tag can process the access

TABLE I. UWBLEE PHY FUNCTIONS IN DIFFERENT MAC STATES

	MAC mode		
	Passive	*Semi-passive*	*Active*
I-UWB	Transmit / receive	Transmit / receive	Transmit / receive
WPT synch	Receive	Receive	Transmit
WPT power	Receive		Transmit
Power source	WPT reception	Battery	Battery
Remarks	Being read or written		Reading or writing other devices

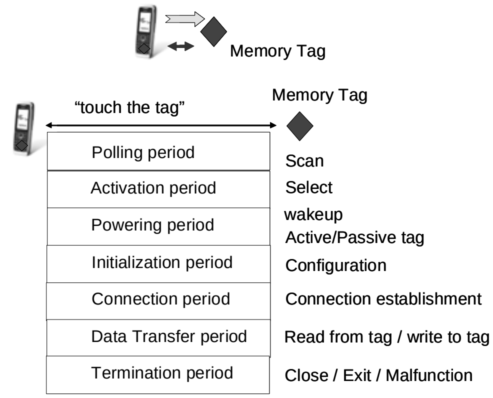

Figure 9. Mobile reader/writer to RF memory tag communication sequence

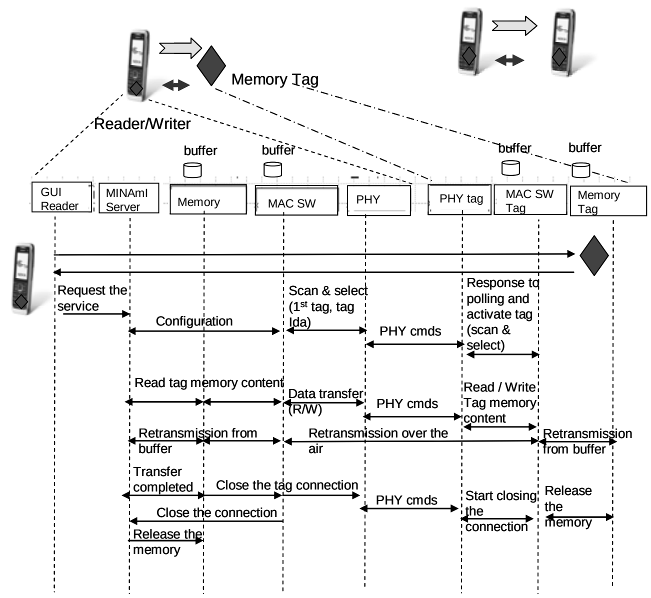

Figure 10. Basic MINAmI subsystem communication setup sequence

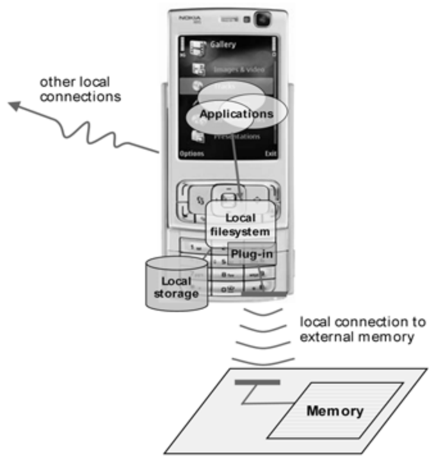

Figure 11. File system view of a mobile phone reading a passive memory tag: a cheap tag without its own processor.

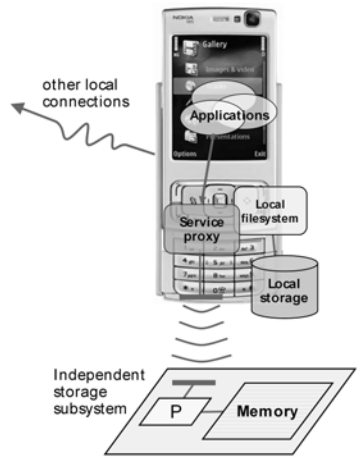

Figure 12. File system view of a mobile phone reading a passive memory: a more expensive tag with its own processor.

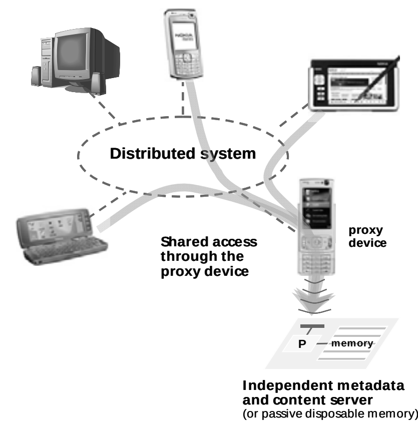

Figure 13. Sharing the content of a passive memory tag.

requests independently and even provide some more advanced services like metadata-based queries. A service proxy relays the service interface of the memory directly to the applications running on the accessing device. The volatile nature of the connection is not a problem if the server is made stateless and transactions atomic.

Device internal modules need to support NoTA to get full benefit of subsystem module independency and still giving fast connection path between subsystems. This interconnect architecture structure allows future extensions for modules within one device.

IV. Results and Discussion

The RF memory tag (i.e. mobile reader/writer and tag) solution is currently under test and integration phase in the MINAmI project. The preliminary technical results are promising and useful for the concept of mobile-phone-readable mass memory tags. The speed of 50Mbit/s has been achieved in technical demonstrations. This shows that mobile reader/writer and the high capacity memory tag is implementable.

The development of a RF memory tag sub-system ongoing in MINAmI project is based on a flexible, FPGA-based hardware platform. The sub-system takes benefit from the ultra-low power UWBLEE transceiver architecture which is suitable for data rates required in RF memory tag applications.

V. Future Development

The UWBLEE wireless connection technology presented in this paper provides data rates and reading ranges significantly exceeding the existing NFC technology already in the market. From technology ecosystem point-of-view there is little sense in developing UWBLEE as an independent technology. UWBLEE can be seen as a possible future high-speed extension to existing RFID technologies, however. The possibility for this should be taken into account in the future development of the two technologies.

In a multi-device environment one device can work as a proxy for the memory tag and provide other devices with access to its services. Even a passive memory tag can be shared this way (see Fig. 13) [27]. Shared access is built around multiple unicast links via a proxy device to the memory tag, where the proxy acts as a reader or writer and performs actual interactions with the tag.

The possibility of using a mobile phone to read a passive tag is, naturally, not the only operational combination of these devices, as shown in Fig. 14. There also are possibilities of, e.g. having the memory tag have its own power source, thus eliminating the need of powering with the WPT signal. In that case, the reading range can be extended or power use within the mobile phone can be reduced, without hindering the performance of the connection. The phone can also communicate directly with other similarly equipped phones.

VI. Conclusions

The evolution of non-volatile memory technologies gives the basis for the vision about RF memory tags. The large

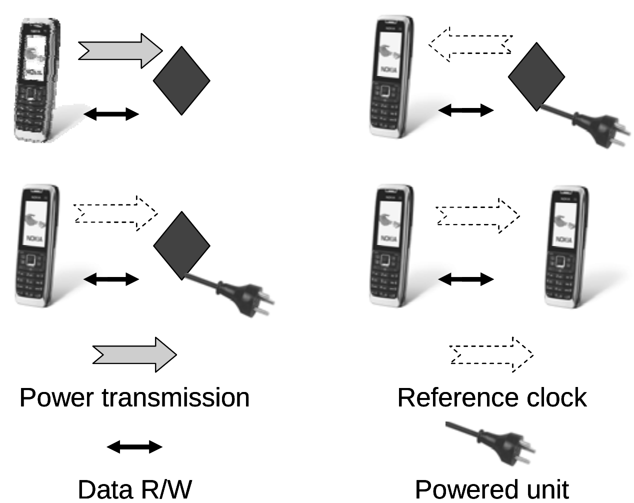

Figure 15. Some possible operational combinations of mobile phones interacting with MINAmI memory tags.

memory, on the other hand, creates a need for a high-speed data connection that can be used to transfer even all the contents of the tags in a timeframe acceptable for the user. The dual-band radio interface, UWB Low End Extension (UWBLEE) presented in this paper, provides the required data rate and possibility for future scalability as memory sizes become larger.

Modular architecture is mandatory in memory tag system to optimize the performance (for example latencies common in memory access of centralized systems are not acceptable). Mobile-centric architecture is evolving towards modular NoTA type approach, where mobile reader/writer and RF memory tag forms one subsystem.

Trend in low-power low-pin-count high-performance interfaces makes the solution feasible. Modern lithography processes and packaging capabilities enable new NVM manufacturing and packaging together with other processes, providing scalable system-on-chip solutions.

Mobile centric architecture is evolving towards modular NoTA type approach, where mobile reader/writer and RF memory tag forms one subsystem.

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