MacZ – a QoS MAC Layer for Ambient Intelligence Systems

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Abstract. Ambient intelligence systems consist of a variety of nodes and applications with different communication needs. To fill these needs, we present MacZ, an adaptive, hybrid Mac layer for wireless ad-hoc networks. MacZ establishes a time-synchronized communication medium, with synchronization across multiple hops. Based on this synchronization, MacZ offers both reservation-based and priority-based communication, and energy saving mechanisms.

1. Motivation

In this work, we present MacZ [1], an adaptive MAC layer for wireless ad-hoc networks that is being developed for the purpose of supporting wireless Ambient Intelligence [2] systems. Ambient Intelligence systems are heterogeneous systems, consisting of a variety of applications and node types with different computational and energy resources. These heterogeneous nodes form a wireless ad-hoc network that is used by applications to gather information or to interact with their environment. The vision is that these networks integrate seamlessly into our everyday life, supporting us in an unobtrusive way.

Today ambient intelligence systems focus on the collection and distribution of sensor data, only giving best-effort guarantees. We believe that the next generation of ambient intelligence systems will support applications that require the communication system to offer stronger Quality of Service guarantees. Especially the large number of independent applications that will be using the same network require a new generation of MAC layers, which are capable of supporting a wide range of different applications, ranging from sensor data collection over the reliable signaling of emergency conditions to the transmission of audio and video streams.

This scenario requires a transmission technology that is able to provide reliable, predictable, energy aware communication services. In this paper, we present MacZ, a QoS MAC layer that creates a time-synchronized medium across multiple hops, providing a slotted multi-hop medium with reservations as well as priority-based frame transmissions.

The remaining part of this paper is structured as follows: Section 2 describes the services and mechanisms of MacZ. Section 3 describes our engineering methodology. Section 4 presents conclusions and future work.

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2. MacZ

With MacZ, we are currently developing a QoS MAC layer that is capable of supporting the needs of the different types of nodes and applications in the ambient intelligence domain. Traditional MAC layers in this domain usually rely either on contention based media access, or on selected master nodes that time-synchronize the nodes that are located around them. MacZ combines these approaches by providing a fully distributed time synchronization of a wireless ad-hoc network across multiple hops, which is based on a virtual clock that synchronizes all nodes relative to a specific event. MacZ has a modular structure and is designed to support a wide range of traffic types, in particular basic communication services for a variety of different, QoS enabled networks that are built on top of it. The scope of MacZ is to provide synchronized, basic media access as a basic service for QoS mechanisms – reservation handling and admission control is left to the upper layers of the protocol stack which also offer concrete guarantees to applications.

To achieve its flexibility, MacZ divides the medium into time slots of different types. The following slot types handling different transmission types are known at the MAC level:

- Slots for reservation-based traffic are subdivided into micro-slots that can be reserved by different applications. The availability of free time slots, as well as the number and size of available slots for reservation-based traffic determine the bounds for reserving bandwidth and delays.
- Slots for contention-based traffic can be used for transmitting either pure best effort traffic, or for priority-based transmissions, by using differently sized contention windows. These slots are usually used for sporadic data, like sensor data or slot reservations.
- Signaling slots are used for signaling specific events that are of interest for all nodes, like alert conditions or the detection of unsynchronized nodes. All nodes have to be awake during these special slots.
- The fourth type of slots is the synchronization slot. The time between two synchronization slots is called a macro-slot, while the slots described above span a specific number of micro-slots. During synchronization slots, all nodes time-synchronize with each other.

By choosing slot size and slot distribution, the networks characteristics can be adapted to the special needs of the current situation. For example, slots for reservation-based traffic may be converted into slots for contention-based traffic. Figure 1 shows a possible slot distribution.

For the synchronization of nodes, a special mechanism, called “black burst transmissions” is used. Black burst transmissions solely rely on the clear channel assessment signal that detects energy on the medium. No frame header, preamble or payload needs to be decoded in order to decode a black burst. The only information that is carried, and thus being decoded, is the length of a burst. This makes black bursts resistant to collisions, as long as their length is not changed significantly. Therefore, no collision avoidance schemes that could delay regular transmissions need to be used for black burst transmissions. However, the medium access layer must ensure that black bursts never interfere with regular transmissions – MacZ solves this problem by providing specific slots for black burst transmissions.

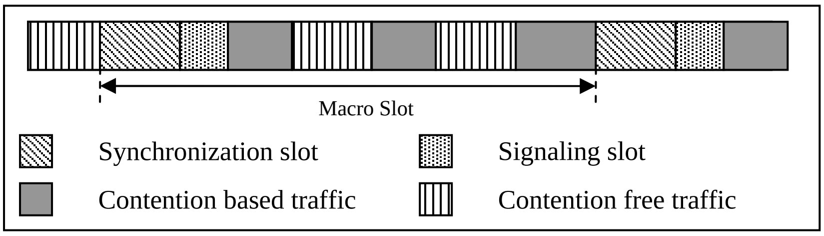

Figure 1: Example slot distribution

The multi-hop synchronization algorithm exploits these characteristics of black bursts to synchronize all nodes to the node that started the synchronization sequence. To distinguish black bursts from regular packets, the length of the smallest transmitted regular packet must exceed the length of a black burst used for synchronization by the factor of 2. If a node receives a synchronization burst, it will forward this burst to all other nodes in its 1-hop distance and repeat this burst for a specific amount of time that depends on the network diameter. If multiple nodes send synchronization bursts at roughly the same time, all nodes will synchronize themselves to the first received burst, also forwarding this burst. With this mechanism, it is guaranteed that the whole network will be synchronized to the node that transmitted the first burst after a certain amount of time that depends on the diameter of the network.

Once the network is synchronized, there are specific synchronization slots in which the nodes will re-synchronize themselves and collect unsynchronized nodes. A node will wait for an amount of time that is greater than the period between two synchronization slots, before it will attempt to start synchronizing the network. This guarantees that nodes will synchronize to an existing network if one is available. By using this distributed algorithm, a network can be synchronized across multiple hops without selecting a specific master node that would provide a single point of failure.

The connected nodes in an ambient network may be of very different types. Some nodes may be connected to a wired network; other nodes may be mobile and have scarce energy resources. This requires MacZ to support multiple energy saving algorithms. Due to the time-synchronization, nodes may go asleep in slots that are not relevant to them. They have even the ability to synchronize with their communication partners to specific best-effort transmission slots for maximum energy savings. These nodes remain synchronized with the network and must be awake during signaling slots. If an alert message is signaled, all nodes will remain active, thus being able to quickly react on the alert message. Nodes that are idle or transmit only very few data may desynchronize from the network and sleep for longer periods of time to save energy. For the network to be able to provide its services, however, a sufficient number of nodes that are available for multi-hop routing or at least during signaling slots must be present.

3. Engineering methodology

To specify MacZ, we use SDL [3], the formal Specification and Description Language. MacZ is divided into two main parts: The MacZ basic layer, which provides the multi-hop synchronization, micro and macro slots as well as signaling slots, and the MacZ service layer, which provides data transmissions during reserved time slots as well as contention-based transmissions and backoff mechanisms.

The MacZ basic layer has already specified, simulated and is partially running on real hardware – the MicaZ motes from Crossbow Industries using a ZigBee compliant transceiver chip. The functionalities of the two layers are specified as micro protocols [4]. Micro protocols are components capturing exactly one protocol functionality and are composed to obtain more complex functionalities

4. Conclusion and future work

We have presented MacZ, our QoS Mac layer for ambient intelligence systems. MacZ is divided into two main components, the MacZ basic layer and the MacZ service layer. While the MacZ basic layer has already been specified, simulated and implemented, specifying the MacZ service layer is ongoing work. We are also working on creating a runtime platform to execute the code generated from SDL systems on embedded devices. Future work includes the safe and dynamic reconfiguration of the MacZ basic services like slot distribution and synchronization mechanisms.

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References

[1] T. Kuhn, I. Fliege. *Micro-protocol based design of a highly adaptive and integrated QoS MAC layer for Ambient Intelligence Systems.* Technical report 347/05, University of Kaiserslautern, 2005.

[2] E. Aarts, R. Harwig, M. Schuurmans. *Ambient intelligence. The invisible future: the seamless integration of technology into everyday life,* Mc-Graw Hill, 2002.

[3] International Telecommunications Union. *Specification and Description Language (SDL).* ITU-T Recommendation Z.100, August 2002.

[4] I. Fliege, A. Geraldy, R. Gotzhein, P. Schaible: *A Flexible Micro Protocol Framework.* In D. Amyot, A.W. Williams (Eds.), System Modeling and Analysis, Lecture Notes in Computer Science 3319, Springer, 2005, pp. 224-236.