Utilization of the IEEE802.11 Power Save Mode with IP Paging

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Abstract— **Mobile communication systems increasingly adopt Internet Protocol solutions for transport of control and data traffic. To optimize scalability of the mobile communication infrastructure as well as to save scarce radio bandwidth and mobile energy resources, mobile devices can enter a power save mode and refrain from sending superfluous location information towards the network in case the device is idle. Such systems utilize paging to locate and reactivate mobile devices in power save mode, as well as to initiate re-establishment of routing information in the network. The well accepted wireless LAN standard IEEE802.11 supports mechanisms for power saving while a mobile terminal is associated with a particular access point. But paging control of mobile devices in power save mode beyond the scope of a single access point is not part of the standard IEEE802.11 application. In this paper, we propose a mechanism to integrate and utilize existing IEEE802.11 power save mode with an IP paging architecture and protocol without the need to modify the IEEE802.11 standard. In addition to the IP paging protocol operation, the proposal covers an appropriate addressing and identification scheme, which can be utilized for other access technologies as well. An analytical evaluation of energy and paging delay costs allows estimation of the proposed mechanism's efficiency, which might be sub-optimal for high load conditions, but appropriate to support migration scenarios towards future heterogeneous access mobile communication networks.**

I. Introduction

Mobile communication systems increasingly adopt Internet Protocol (IP) solutions for mobility management. Various protocols and associated architecture components are being specified to allow efficient location tracking and routing state maintenance to grant reachability of mobile devices. All mobility management protocols imply signaling between the mobile terminal and the network infrastructure to maintain a mobile device's routing states in the network, supporting continuous delivery of data packets towards individual mobile devices. While a mobile device receives data packets through the mobile communication system's infrastructure, handover management aims at optimization of data delivery in case of a mobile device has to re-associate with a new wireless access point. On the other hand, if a mobile device does not participate in a data session, location management supports continuous tracking of individual mobile terminals' location to grant reachability. Taking into account that only a fraction of powered mobile terminals participate in a data session at a time, maintaining a high degree of accuracy of individual mobile terminals' location implies superfluous waste of wireless bandwidth and the mobile devices' battery energy due to frequent transmission of location update signaling from the mobile device towards the network infrastructure.

To optimize location tracking and to support saving power on idle mobile devices, mobile communication systems could allow these mobile devices to enter a *dormant* state to save power. Mobile devices in dormant state are then relieved from sending location updates while roaming within an enlarged area, which is the *paging area*. In case of data packets are to be forwarded to a mobile device in dormant state, mobile communication systems utilize paging mechanisms to locate and re-activate a mobile terminal. A paging procedure makes use of signaling to poll individual locations of a paging area, aiming at location and re-activation of the paged mobile device, as well as updating its routing states in the network to allow data packets being forwarded to their final destination. While being in dormant state, a mobile device could also switch its network interface card (NIC) into a power save mode (PSM), which reduces transmit (Tx) and receive (Rx) activity to save energy resources. Most efficient means to save energy would be to switch off the network interface or even the mobile device entirely. However, this implies that the mobile device is not reachable anymore. To remain reachable, a mobile device must be able to listen to paging related signaling, hence, some activity of the device's network interface is still required. Usually, the control of PSM and the availability of paging indication mechanisms is technology dependent. Integration with a paging system might require adaptation of the standard access technology to allow control of power save mode specific functions.

In this paper we present a solution for IEEE802.11 PSM [1] integration with an IP paging system, which allows utilization of IEEE802.11 PSM without the need to modify IEEE802.11 access points. Even if the efficiency of power saving could be improved with adapted standard IEEE802.11 mechanisms, the proposed solution represents a valuable approach to support initial integration and migration scenarios towards future mobile communications systems.

II. Related work

A variety of IP paging protocols have been proposed throughout the last years. Most proposals focus on the IP-based paging architecture and an associated protocol operation to perform location tracking of idle mobile devices within a paging area, support for paging area update signaling in case of a mobile terminal enters a new paging area while being dormant, as well as on the actual IP paging process. Most proposals do not consider how to identify and address the dormant mobile terminal, which might not have a valid IP address due to its reduced activity in dormant state. Their focus is rather on saving signaling costs without taking support for technology specific power save mechanisms into account at all.

In [2], the authors utilize the unicast data delivery scheme for mobile devices in IEEE802.11 PSM and refer to a paging extension for Hierarchical Mobile-IPv6 as IP paging solution. The authors aim at a performance evaluation of the mentioned IP paging protocol in IEEE802.11 networks, but do not address how the mapping between the IP paging protocol and IEEE802.11 traffic indication for mobile terminals in PSM is done. It is assumed, that access points can associate a received paging request message with an Association Identifier of the paged mobile terminal. This is only possible in case a mobile device has associated with an access point and the paging request signaling messages address the mobile terminal's unicast address, which needs to be known to the access point. Hence, the actual IP paging solution does not play any role in the evaluation and the authors focus on deriving the paging delay and the session blocking probability metric, taking the standard access point's traffic identification scheme into account without considering the entire paging system.

The paging architecture described in [3] places most paging related functional entities into access routers. This makes it potentially possible to perform mapping of the described paging protocol to technology specific power save mode control and paging indication at the access router, but such a functionality is not covered in the description. The protocol does also not refer to any mobile device identification and addressing scheme, which can be utilized during the paging procedure.

In [4], we proposed a paging architecture and protocol, which represents a compromise between flexibility and protocol complexity. Further design goals have been taken into account, like support for enhanced paging strategies and means to map the technology independent IP paging protocol to technology specific functions with the help of paging attendant functions. The protocol design follows the associated requirements for paging protocols [5], which have been published by the Internet Engineering Task Force (IETF). An evaluation of the proposed paging architecture and protocol, as well as a comparison of associated signaling costs with the P-MIP protocol [3] can be found in [4].

For the integration of IEEE802.11 PSM with an IP paging system as described in this paper, we utilize the architecture and protocol according to [4], which is briefly summarized in section III-A and III-B.

III. THE PAGING ARCHITECTURE AND PROTOCOL OPERATION

The architecture we specified follows functional and non-functional requirements as discussed in the IETF document [5], and incorporates the defined basic functional entities for paging. These functional entities comprise a Dormant Monitoring Agent function (DMA), which buffers IP data packets being addressed to mobile terminals in power save mode. After a successful paging process, the DMA function forwards buffered data packets to their final destination. The control part of the architecture comprises a Tracking Agent function (TA) as well as a Paging Agent function (PA). The TA function tracks the mobiles' location with the granularity of a paging area, whereas the PA function coordinates the paging procedure within a registered paging area.

A. *Paging Architecture*

In this paper, we make use of a generic architecture and protocol for IP-based paging, which is described in detail in [4]. A characteristic of this architecture's design is that it collocates and distributes paging functional entities efficiently to allow flexible use of a common protocol for location tracking- and paging- related signaling within the infrastructure. Furthermore, it supports mapping of the common IP paging protocol to technology specific control functions within access networks with the help of paging attendant functions. Full control of the paging procedure is dedicated to a Paging Controller entity, which implements the TA function and the DMA function. The PA function is dedicated to coordinate the paging process. We split the PA function into two sub-functions. The generic function, which is independent of access technology specifics and dedicated to coordinate polling the paging area with associated IP-based signaling messages during the paging process, is also collocated with the Paging Controller entity. The previously introduced paging attendant function represents the remaining part of the PA functional split and is responsible for the paging protocol mapping as referred to above.

The paging architecture we utilize for the integration of the IEEE802.11 power save mode comprises the Paging Controller entity, which is located in the infrastructure's core network, and distributed paging attendant functions. Paging attendant functions are collocated with access routers for the functionality described in this paper. A client paging coordination function is collocated with the mobile terminal, which maintains the terminal's state and coordinates the protocol operation associated with IP paging. In this paper, the Paging Controller is assumed to be able to receive data packets being destined to mobile terminals in power save mode at the integrated DMA function.

B. *Protocol Operation*

For the mechanism described in this paper, we refer to a mobile terminal's state to be either *Active* or *Dormant*. In *Active* state, the network knows the mobile terminal's exact location and associated routing information. The Paging

Controller does not maintain a registration of mobile terminals in *Active* state. In *Dormant* state, data packets being addressed to the mobile terminal arrive at the Paging Controller for being buffered and trigger the paging procedure, which requires the mobile terminal to register with the Paging Controller before entering *Dormant* state.

The basic protocol operation for registration, paging and de-registration is illustrated in Fig. 1. When a mobile terminal decides to enter *Dormant* state, it sends a Dormant Request message with an associated registration lifetime and the current paging area's identifier to the paging attendant function collocated with the mobile terminal's current access router. Further information is added to allow building a *paging identifier* (PID) for mobile terminals in *Dormant* state. Details about the PID and how it supports addressing dormant mobile terminals are described in section III-C. The paging attendant function forwards the Dormant Request to the Paging Controller. The Paging Controller generates a registration entry for the mobile terminal and replies with a Dormant Reply message through the paging attendant. The Dormant Reply comprises the mobile terminal's final PID, which supports unique identification of a mobile terminal in *Dormant* state. As soon as the mobile terminal receives the Dormant Reply message, it changes its state from *Active* to *Dormant*. The authors refer to additional signaling, which might be required to redirect packets towards the Paging Controller while a mobile terminal is dormant. This operation is not relevant for the mechanisms described in this paper and the reader is referred to [4] for more details.

When a mobile terminal is to be paged due to incoming traffic, the Paging Controller distributes Paging Request messages to all paging attendant functions being associated with the registered paging area. The Paging Request message comprises the mobile terminal's PID. On reception of the Paging Request, each attendant function builds an on-link Paging Request message according to the PID and sends the Paging Request towards mobile terminals.

The paged mobile terminal receives the Paging Request message through one of the access routers associated with the registered paging area. After verification and validation of the PID, the mobile terminal de-registers with the Paging Controller by means of sending an Activate Request message to the Paging Controller through its current access router's paging attendant. In addition to the PID, the Activate Request message comprises information about the terminal's current location to allow re-establishment of associated routing states and forwarding of buffered data packets. Before deleting the registration entry of the mobile terminal, the Paging Controller sends an Activate Reply message to the mobile terminal to acknowledge the de-registration operation. On reception of the Activate Reply message, the mobile terminal sets its state to *Active*.

C. Addressing and Identification Scheme

Mobile terminals in *Dormant* state might reduce interface activity and refrain from maintenance of location information

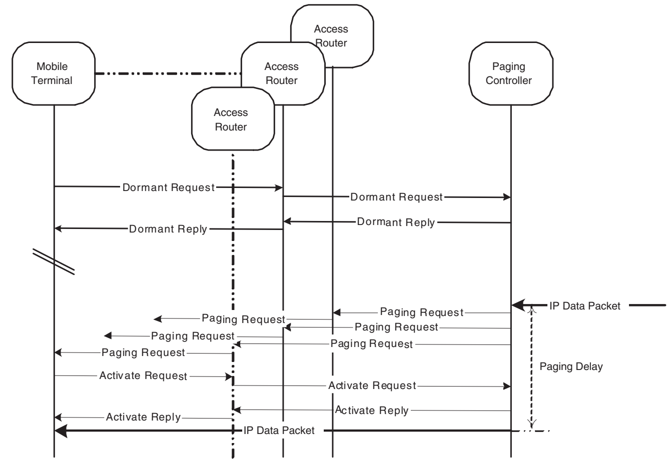

Fig. 1. MSC of the basic paging protocol operation.

and associated routing states in the network. The paging procedure allows to cope with outdated routing states in the network and supports locating a mobile device as well as to initiate re-establishment of routing states. A so far open issue is how to identify and address mobile terminals during a paging process on IP layer, taking into account that IP address(es) of paged mobile terminals might be obsolete. We focus on the identification and addressing issue in this section, where we propose the format of a PID. This identifier can be used for unique identification of mobile terminals in *Dormant* state and at the same time allows the derivation of an IPv6 Solicited Node Multicast address to address an IP Paging Request to a dormant mobile terminal on the (wireless) access link. Solicited Node Multicast addresses are utilized in the IPv6 Neighbor Discovery procedure [6] and allow addressing a single entity with a high probability of uniqueness, since it has MAC address parts of the respective mobile terminal's NIC incorporated. Each mobile terminal listens by default to at least one Solicited Node Multicast address per interface, which is based on the interface's MAC address. The Solicited Node Multicast address comprises a prefix and an identification part. The latter fraction of the address represents the last 3 byte of the mobile terminal NIC's MAC address. The format of the Solicited Node Multicast address is illustrated in Fig. 2.

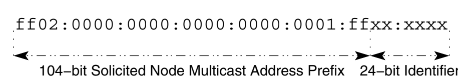

Fig. 2. The Solicited Node Multicast-based addressing scheme.

The general idea of the paging identifier (PID) is to incorporate the 3 least significant byte of the MAC address of each NIC implemented with the mobile terminal as *Interface ID*. Each of these three bytes are added two further fields, indicating the NIC type (IEEE802.11, Bluetooth, CDMA, ...) and the actual length of this particular identifier fraction. The general format of a PID is illustrated in Fig. 3. To build the PID, a mobile terminal must send relevant information about all implemented and powered NICs' MAC addresses to the Paging Controller during the registration procedure. The Paging Controller can add some more information to the *ID Extension* field of the PID header to assure uniqueness of the ID and send the final PID back to the mobile terminal in the registration reply message.

During a paging process, paging attendant functions within the access network retrieve the PID from the received Paging Request message. According to the network technology being supported by the paging attendant, the appropriate MAC address part of the associated technology is used to build the mobile device's Solicited Node Multicast address, which serves then as destination address for the IP Paging Request released towards mobile terminals. On reception of the Paging Request, the mobile terminal can prepare *Active* state transition (IP address acquisition, re-association with the network, etc.) and de-registration with the Paging Controller to retrieve buffered data packets.

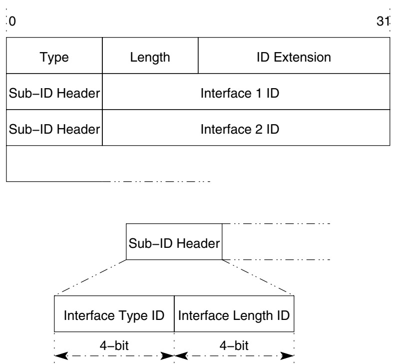

Fig. 3. Unique identification of dormant mobile devices.

IV. The Standard IEEE802.11 Power Save Mode

The IEEE802.11 standard [1] comprises mechanisms for power saving as well as for associated traffic indication and delivery. PSM for ad-hoc as well as infrastructure based networks are described, but we focus here only on the infrastructure mode. The mechanism for traffic indication and data delivery to mobile devices in PSM is different for unicast and multicast data packets and is supported only while a mobile device remains associated with a particular access point. Power saving is achieved by means of switching the mobile device's NIC state from permanent transmit and receive capability (*RxTx* state) to a *Doze* state. In *Doze* state, a NIC reduces its activity and is able to receive traffic only at regular intervals, which is a multiple of the beacon interval (BI). A beacon is an IEEE802.11 specific management frame, which is periodically advertised from access points for synchronization and information purposes.

After a mobile device has selected an access point, it performs an authentication and association procedure. Throughout the association procedure, the mobile device informs the access point about its *Listen Interval* parameter, which indicates the amount of beacon intervals a NIC remains unreachable before listening to the next beacon. Furthermore, the access point assigns the mobile device's NIC an Association Identifier (*AID*). The AID is used for unicast traffic indication to an individual mobile device in PSM and represents a bit in the traffic indication bitmap (TIM), which is sent with each beacon. When entering PSM, a mobile device indicates its mode in an IEEE802.11 specific frame control field. From now on, the access point listens to data packets destined to the mobile device's IP address. As soon as a packet for a mobile device in PSM is received, the packet is buffered at the access point and traffic is indicated to the mobile device in subsequent beacons' TIM information element. As soon as a mobile device finds traffic indicated in a received TIM, it polls buffered data packets from the access point with an IEEE802.11 specific Power Save Poll (PSP) message.

Delivery of multicast traffic is different and not indicated to individual mobile devices. Multicast packets are buffered at the access point instead and sent towards mobile devices at regular intervals, which is a multiple of the BI. To allow mobile devices knowing about when they have to listen to multicast packets, advertised beacons comprise a Delivery Traffic Indication Map (DTIM) value, which is administratively configured at access points and represents the multicast traffic delivery interval as a multiple of a BI. To allow synchronization with periodic multicast delivery, beacons advertise a DTIM Counter indication, which refers to the amount of remaining beacons before multicast traffic is being sent. With the help of this information, a mobile device learns about when it has to prepare for receiving multicast packets. After reception of a multicast frame from an access point, a *MoreData* flag in the frame control header indicates that a further multicast packet has been buffered at the access point and will be sent subsequently. After all buffered multicast frames have been forwarded, the mobile device's NIC can reduce activity again until the next DTIM period approaches or unicast traffic is being indicated to the device.

V. View of an Integrated System

To control the paging procedure from the network and at the same time utilize IEEE802.11 PSM mechanisms without any modification in a first step towards future heterogeneous access networks should motivate the work described in this paper. We focus on the IEEE802.11 multicast delivery scheme for mobile devices in PSM. A core conceptual approach of the integration is to relocate processing of user data packets from the access points to the Paging Controller and to utilize the multicast delivery scheme of access points to convey Paging Request signaling messages towards mobile terminals in PSM.

The architecture of the integrated system comprises the Paging Controller, paging attendants, which are here collocated with the access network's access routers, and one or more access points being connected to each access router to provide wireless access to the infrastructure. Fig. 4 illustrates the architecture components and the protocol operation, the mobile terminal state as well as an activity profile of the mobile terminal's NIC based on the NIC state.

To save power during idle periods, mobile terminals enter *Dormant* state transition and initiate the registration with the Paging Controller according to the procedure described in section III-B. The Dormant Request message carries the relevant IEEE802.11 NIC's MAC address information to allow building the complete PID at the Paging Controller. The Paging Controller checks the PID's uniqueness by means of comparing the built PID with PIDs of other registrations maintained. In case there is a PID conflict due to a match of the last 24 bit in the MAC address(es) of registered mobile terminals, the Paging Controller could add an appropriate value to the *ID Extension* field of the PID header to achieve uniqueness. The validated PID is sent to the mobile terminal in the Dormant Reply message. On reception of the reply to the registration request, the mobile terminal enters *Dormant* state and switches its IEEE802.11 NIC to *Doze* mode to save energy.

In case a data packet is destined to a dormant mobile terminal, the data packet is buffered at the Paging Controller and the paging procedure is initiated. The Controller sends the Paging Request message to the paging area's access routers and the collocated paging attendants build the on-link Paging Request message, which is addressed to the mobile terminal's Solicited Node Multicast address. After the paging attendants have released the Paging Request message, access points buffer the multicast-type Paging Request and release all buffered packets, which have accumulated in the PSM queue during a DTIM period, when the DTIM counter reaches "0". After reception of the Paging Request message, which is processed on IPv6 protocol layer only by mobile terminals matching the messages' Solicited Node Multicast address, de-registration with the Paging Controller is initiated after the NIC has been switched to *RxTx* mode.

One has to remark, that the PID supports unique identification on IP layer, but does not entirely eliminate the issue of an address conflict of the Solicited Node Multicast address. This can cause that more than one mobile terminal is addressed with a Paging Request in case of the terminals' NIC have the same 3 least significant byte in the MAC address and they are located in the same paging area. This conflict must be resolved on the IP paging protocol layer, where the misleadingly paged mobile terminal should be notified to re-enter dormant state. This can be done with an appropriate status code indication in a Dormant Reply message and is out of the scope of this paper.

An important characteristic of the proposed integrated concept is that it comprises similar states and procedures as utilized by current cellular networks where paging control is dedicated to components in the network infrastructure. Mobile terminals save most power during an idle period while no data is transmitted or received. While data is transmitted and received, other mechanisms might support saving power during this busy phase, which is beyond the scope of this paper. Hence, during *Active* state, a mobile terminal's NIC mode is referred to be in *RxTx* state here.

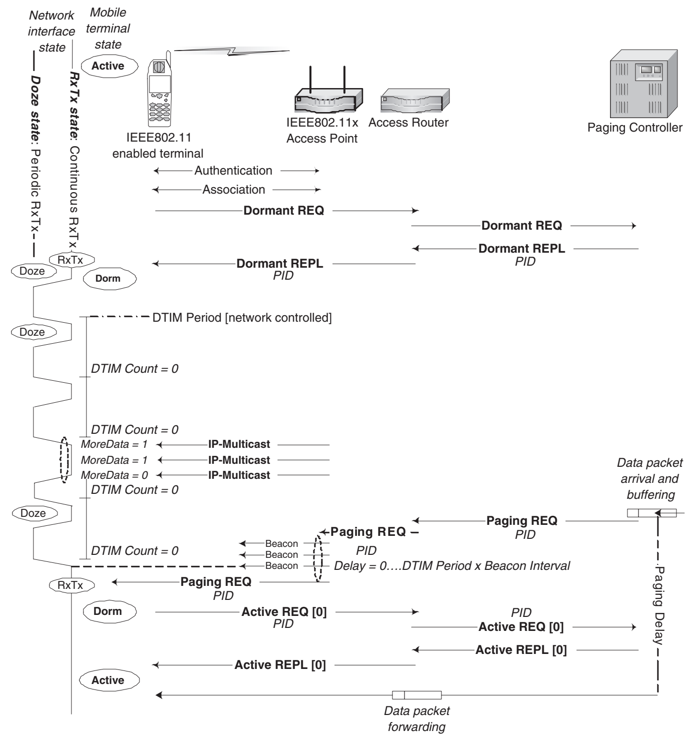

Fig. 4. IP paging with IEEE802.11 PSM utilizing the DTIM count mechanism.

VI. Performance Evaluation

Introducing paging functionality with a mobile communication system can improve system capacity and availability of energy resources on mobile devices. As drawback, to locate and re-activate a dormant mobile device on reception of an initial data packet introduces additional latency in routing of initial data packets. An important metric, which characterizes a paging architecture and the associated protocol operation, is the additional routing delay due to paging and power save mode control. This *paging delay* affects the overall routing delay from a data source to the packet's final destination and it is an application characteristic to be either more or less sensitive with regard to routing delay. In a worst case, a data session might be blocked due to a timeout caused by exceeding the overall routing delay constraint.

To estimate the dependency of the proposed mechanism's power saving efficiency and paging delay on load conditions as well as on system- and data session characteristics, we refer to an analytical model representing the characteristics of utilizing the IEEE802.11 power save mode for multicast delivery with the proposed IP paging protocol. For a qualitative analysis, we evaluate a total costs metric (C_{total}), which comprises the paging delay costs (C_{delay}) and the energy costs (C_{energy}).

$$C_{total} = C_{delay} + C_{energy} \quad (1)$$

The paging delay is affected through the link delay characteristics between the Paging Controller and the mobile device, as well as through the PSM characteristics of the IEEE802.11

access point, taking the queuing delay and deterministic multicast delivery of Paging Request signaling messages into account. The energy efficiency depends on the amount of time a mobile device's NIC can remain in *Doze* mode while being dormant between two data sessions.

A. Model to determine the Total Costs

A main characteristic and drawback associated with the PSM for multicast delivery is that multicast-type frames are buffered at the access points throughout the DTIM period. Each time the DTIM counter reaches 0, the buffer is emptied by means of transmitting each Paging Request, one after the other, which introduces a delay in routing a particular Paging Request. Fig. 5 illustrates the components affecting the downlink paging delay. Initial data packets of multiple traffic sources arrive at the Paging Controller, where they are buffered throughout the paging procedure. The Paging Controller releases one Paging Request message towards each access router of the registered paging area. Each access router builds a last hop Paging Request message, addressing the Solicited Node Multicast address of the paged mobile device. Throughout a DTIM period, all Paging Request messages are buffered at individual access points and are released with an IEEE802.11 specific wireless processing rate (μ_w) when the DTIM counter reaches 0. Link delays are assumed to be constant for this qualitative evaluation. The wireless transmission delay comprises the wireless transmission speed including contention for medium access and backoff. The time elapsed between the arrival of a data packet at the Paging Controller and the arrival of the Paging Request message at the mobile device represents the downlink paging delay (d_d). To allow forwarding of buffered data packets, the mobile device must send a de-registration message (Activate Request) to the Paging Controller including its location information. The uplink de-registration message experiences an uplink delay (d_u), which is affected by the IEEE802.11 specific wireless delay $(d_w = 1/\mu_w)$ and a wired link delay (d_l) between the access point and the Paging Controller. The queuing delay of

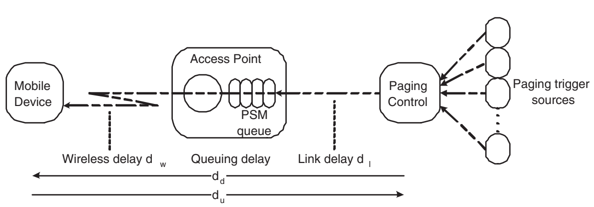

Fig. 5. Illustration of components and parameters affecting the paging delay.

Paging Request messages within the access point is affected by the DTIM period, which is a multiple of a beacon interval $(\rho \cdot BI)$. Furthermore, the multicast frames, which have been received at an access point during the DTIM period before the Paging Request of interest, and the wireless delay affect the queuing delay. Arrival of a Paging Request at the access point is assumed to be uniformly distributed throughout the DTIM period. The delay characteristic at an access point is illustrated in Fig. 6. The mean downlink delay including the delay caused by the transmission of N previously received multicast frames can be calculated according to (2).

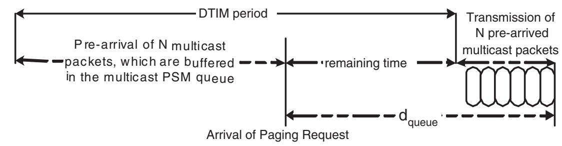

Fig. 6. Illustration of a model to determine the queuing delay at an access point.

$$\begin{aligned} d_d &= (\int_{d_l+d_w}^{d_l+d_w+\rho \cdot BI} \frac{1}{\rho \cdot BI} \cdot t \cdot dt) + N \cdot d_w \\ &= d_l + d_w + \tfrac{1}{2} \cdot \rho \cdot BI + N \cdot d_w \end{aligned} \quad (2)$$

The total paging delay d_p comprises the downlink delay and the uplink delay $(d_u = d_w + d_l)$ between the mobile device and the Paging Controller.

$$\begin{aligned} d_p &= d_l + d_w + \frac{1}{2} \cdot \rho \cdot BI + N \cdot d_w + d_w + d_l \\ &= 2 \cdot d_l + (2+N) \cdot d_w + \tfrac{1}{2} \cdot \rho \cdot BI \end{aligned} \quad (3)$$

The delay costs are assumed to be proportional to the paging delay:

$$C_{delay} = \beta \cdot d_p, \quad (4)$$

where β denotes the costs per second delay. To determine a metric for power saving efficiency, we derive the fraction of the period between two subsequent sessions, where a mobile device can reduce its activity and neither sends nor receives traffic. To subdivide the time between two session starts, we define the session duration (SD), the timeout value (T), which causes a mobile device to enter *dormant* state and PSM after the end of a session, and the idle duration (ID). While being idle, a mobile device listens to Paging Request packets every DTIM period. The energy costs during the inter-session interval (IS) is proportional to the time a mobile device's NIC is either in *RxTx* state or listens to multicast frames each DTIM period for the time consumed to deliver buffered multicast frames. The energy costs can be calculated as follows:

$$C_{energy} = \alpha \cdot K, \quad (5)$$

where K refers to the relative time a NIC consumes energy to receive or send data and α denotes the unit of costs per second of activity. Referring to Fig. 4, a NIC consumes energy in *RxTx* state as well as at each DTIM period throughout the delivery of buffered multicast frames and implies *activity* for listening to the medium, sending or receiving. Efficient *energy saving* is possible during the remaining periods while the NIC is in *Doze* mode without sensing the medium for traffic. K can be derived from the model referred to in Fig. 7.

$$K = \frac{1}{AD+T+ID} \cdot (AD + T + \lfloor \frac{ID}{\rho \cdot BI} \rfloor \cdot N \cdot d_w), \quad (6)$$

where the term $N \cdot d_w$ determines the mean duration of activity each DTIM period due to the delivery and processing of all buffered multicast packets.

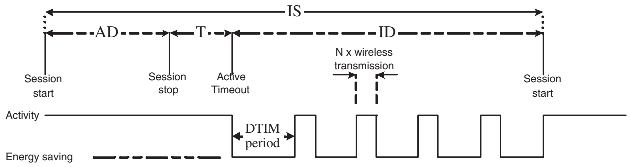

Fig. 7. Determination of the energy costs representing relative activity during the period between two session starts.

B. Analytical Evaluation

To estimate the costs efficiency of the proposed power saving and paging scheme, we evaluate the impact of the session interval (IS), the multicast traffic load (N) on a particular access point and the DTIM period ($\rho \cdot BI$) to the total costs. Mobility of end-devices and associated handover control is not being taken into account for this evaluation. We assume a session active duration (AD) of 30 seconds, a timeout (T) of 5 seconds and the costs units for the paging delay β and the relative energy consumption α to be 1. The costs are evaluated for a session interval parameter between 35 seconds and 200 seconds, whereas the multicast PSM buffer load on a particular access point is increased up to 20 previously arrived multicast packets, which are buffered in the PSM queue throughout the relevant DTIM period. The link delay and the wireless delay are assumed to be constant for this analysis and have been assigned 5 milliseconds and 10 milliseconds respectively. Fig. 8 illustrates the total costs for two different DTIM period settings, having ρ set to 2 (”rho2_beta1”) and to 10 (”rho10_beta1”) respectively, where the beacon interval is assumed to be constantly 100 milliseconds.

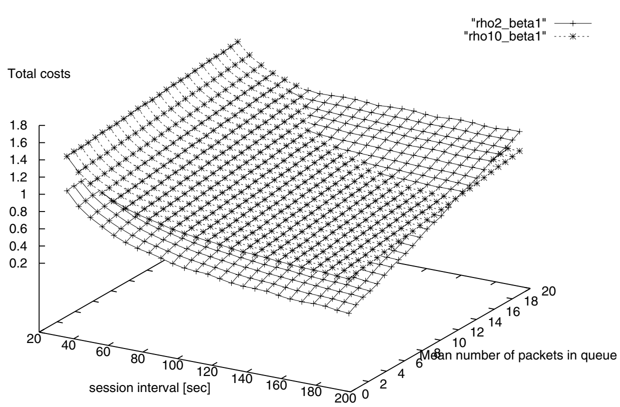

Fig. 8. Total costs as a function of session start interval and load of the multicast-delivery buffer at IEEE802.11 access points.

For low multicast traffic load, the impact of the paging delay costs is less because the multicast PSM queue does not introduce a major delay. Furthermore, since the active period to receive buffered multicast traffic each DTIM period is small compared to the DTIM period, energy saving efficiency is noticeable because the fraction of activity is less relative to the DTIM period. This causes the energy costs to decrease with an increasing session interval. Increasing the multicast load on the PSM queue (N) causes the active period throughout a DTIM period to approach more and more the value of the DTIM period, hence, energy saving efficiency decreases for higher load and approaches more and more a constant level. Increasing the DTIM period ($\rho = 10$), the impact of the load gets less, because even for a major amount of multicast packets being transmitted each DTIM period, the fraction of inactivity (energy saving) throughout a DTIM period is large enough. However, one can see that for low load condition, the delay caused by the increased DTIM period has impact on the total costs and compensates some gain in costs contributed by the energy costs.

VII. Conclusion

In this paper we proposed a modular integration and utilization of an IEEE802.11 power saving mechanism with an IP paging protocol to support migration scenarios towards future heterogeneous mobile communication networks. An analytical evaluation of an energy and delay costs metric allowed to derive dependency of the proposed mechanism’s efficiency on the idle period characteristics, as well as on the load condition within the IEEE802.11 access points’ multicast power save queue and on the selected DTIM period. Even if the proposed mechanism’s power save efficiency is sub-optimal for high load and the delay costs increase for large DTIM period values, the modular integration scheme allows quick integration and control of the IEEE802.11 power save mechanism throughout the migration phase towards future heterogeneous IP-based mobile communication networks without the need to modify the IEEE802.11 standard. To be efficient, the DTIM period has to be chosen appropriately to not increase the paging delay too much, even if this limits the power saving characteristics. As a next step, various access technologies and associated standards can be adapted to support smoother and optimized integration of technologies with future IP-based mobile communication networks.

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