

A Network Connectivity Power-Saving Mechanism for Mobile Devices in DLNA Home Networks

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Abstract—Mobile devices are increasingly assuming an important role in “smart home” network environments. Although their computing, storage and networking capabilities have evolved significantly, these devices remain power-constrained and, therefore, need to actively take measures to minimize their power consumption. In this paper, we propose a Network Connectivity Power Saving (NC-PS) mechanism for mobile devices in Digital Living Network Alliance (DLNA) home networks, which allows them to conserve power without compromising their higher-layer functionality. The proposed mechanism introduces a level of indirection that abstracts the low-level low-power support of different wireless bearers and exposes a uniform interface to higher-layer entities, such as applications and Universal-Plug-and-Play (UPnP) agents. We define four abstract NC-PS modes and we describe their mapping in the case of Bluetooth, a common wireless bearer for mobile devices, now supported in DLNA.

Keywords: *wireless home networks, DLNA, power management.*

I. INTRODUCTION

The wide availability of inexpensive networking technologies, such as 802.11 Wireless Local Area Networks (WLAN) [1] and Bluetooth Wireless Personal Area Networks (WPAN) [2], have recently led to the rapid proliferation of home networks. Increasingly, the use of these networks is expected to move from more traditional computer networking applications (e.g. network printing, web browsing, file sharing) to new consumer-oriented applications currently provided by stand-alone devices (e.g. video and music playback and recording). Industry initiatives, such as the DLNA [3] and UPnP Forum [4], aim at enabling such “smart homes” by ensuring interoperability among networked devices from the Consumer Electronics (CE), Mobile and Personal Computer (PC) industries. In particular, mobile devices (e.g. smart-phones) with their increasing multimedia and networking capabilities are expected to be first-class citizens in this digital “smart home” ecosystem.

Version 1.0 of DLNA interoperability guidelines [5] addressed home networked devices which are in general static and not power-constrained. The new version of the DLNA guidelines [6] also introduces Mobile Handheld Devices (MHD), which are in general mobile, power-constrained devices, such as mobile phones, PDA’s, and portable music players. The new guidelines address a number of issues related

to operating MHDs in a DLNA home network, among which network connectivity. To connect to a DLNA home network, an MHD needs to connect via an Access Point (AP), which bridges between the MHD domain and the rest of the home network. The DLNA is recommending the use of the Mobile Network Connectivity Function (M-NCF), which defines the functionality that should be implemented by DLNA-compliant APs to support MHDs. Currently, the guidelines specify only Bluetooth M-NCF, but other wireless bearers may be added in the future.

One of the additional functionalities provided by an M-NCF compared to an off-the-self AP is a mechanism to collaborate with MHD to reduce power consumption. When an MHD is connected to the home network using a wireless bearer, an active connection is maintained between the MHD and an M-NCF. An active connection causes increased power consumption for the MHD, as compared to when the MHD is not connected to the home network. Consumers would like to be able to use their MHDs to connect to the home networks without noticing a significant reduction in the battery duration of their devices. Therefore, there is a need for a mechanism that would allow MHDs and M-NCFs to collaborate and manage their connection to save battery power.

In this paper, we present our proposal for a Network Connectivity Power Saving (NC-PS) mechanism between an MHD and an M-NCF. This proposal formed the basis of the NC-PS mechanism adopted in DLNA [6]. In this sense, this paper describes the basic ideas behind the adopted DLNA NC-PS mechanism, although not the exact mechanism itself¹. The proposed mechanism exposes a bearer-independent interface to applications, agents and other higher-layer entities and translates these abstract NC-PS modes to the appropriate native low-power states of the wireless bearer used. In this way, the power saving behavior as seen by higher-layer entities does not depend on the specifics of the wireless bearer used. Furthermore, the proposed mechanism leverages native wireless bearer protocol messages to avoid the introduction of a new NC-PS protocol between the MHDs and the M-NCFs. In addition, it specifies a number of permissible operations that reduce the flow of control-traffic between the MHD and the

¹ Note that this paper expresses only our personal views. For the actual DLNA guidelines we refer interested readers to DLNA [3], [6].

M-NCF, without compromising the higher-layer functionality of the MHDs. Finally, although typically an MHD would also take other measures (e.g. processor in a low power state, turn-off screen), these are beyond the scope of this paper.

The rest of this paper is organized as follows: Section II presents the related work in this area; Section III gives an example usage scenario; Section IV presents a brief overview of the DLNA network architecture representing the context of the proposed mechanism; Section V describes in detail the proposed NC-PS mechanism; finally, Section VI gives the conclusions of this work.

II. RELATED WORK

Power management research can be divided into two main categories: the first one (e.g. [7]) is looking on how systems can internally manage energy consumption, e.g. by switching off some system components; the second (e.g. [8]) aims at optimizing protocols and network functionality so that power consumption is balanced with system performance. The mechanism we propose in this paper falls in the latter category. In both areas, the challenge is to minimize energy consumption without significantly compromising the user experience.

At the link-level, power management is usually achieved by keeping the transmission power at the minimum necessary level and by allowing periodic connectivity with a small duty cycle. This is the typical approach in cellular networks. Local connectivity bearers, such as 802.11 or Bluetooth, support power management at the MAC layer with support of power management circuitry. In the original 802.11 specification [1], power management is based on the idea that the WLAN clients inform the AP before entering in a power saving mode and then periodically listen to Access Point beacons for incoming traffic buffered for them. The new standard 802.11e [9] has defined a more elaborate scheme, where transmission times can be defined more deterministically (e.g. for VoIP traffic). The Bluetooth power saving [2] mechanism is also based on periodic wake-up with small duty cycles. For instance, the ‘sniff’ mode resembles the 802.11 power-save mode allowing fast resumption of active communications, while the ‘hold’ and ‘park’ modes are intended for longer standby times.

Power management is very important in ad-hoc networking since many of these devices (e.g. sensors) are very energy-constrained. Some of the ad-hoc routing protocols aim at selecting energy efficient routes [10]. Although these techniques are interesting in general, deploying them in home networks is usually challenging.

The Consumer Electronics Association (CEA) has addressed power saving for networked home A/V devices in [11]. Power management is defined as a very generic framework. The CEA approach specifically excludes network infrastructure devices, e.g. routers, DHCP servers, and wireless Access Points. All other devices should implement some or all of the following states: 1.Disconnected/off, 2.Local Standby,

3.Network Standby, 4.Listen, 5.Active.

Finally, the UPnP Forum has an on going activity to define a power management framework for UPnP-enabled devices. In the CEA classification, this work applies mostly to states 1, 4 and 5, but could also be applied to state 3 through an out-of-band (i.e. non-IP-based) wake-up mechanism. The approach of the UPnP Forum is to optimize the energy consumption while keeping the devices discoverable by UPnP control points. In this approach there are additional power states that allow more fine-grained power management between the ‘Active’ and ‘Listen’ CEA states defined in [11].

III. AN EXAMPLE USAGE SCENARIO

Bob purchases a new home-network enabled mobile phone and is thrilled to discover that he can now control his networked Digital Video Recorder (DVR) with it. One day, he uses the phone to view the day’s recording schedule and then leaves it on the table nearby and forgets about it, without disconnecting from the home-network properly. Several hours later, he sees the phone on the table and he remembers that he did not follow the right procedure to disconnect. He immediately goes for the charger because he assumes that the battery must need to be recharged by now, but he is pleasantly surprised to find out that it has not discharged noticeably.

Bob does not know that his new phone and Bluetooth AP implement an NC-PS mechanism to save battery power. The phone decides to put the link between it and the Bluetooth AP in the ‘Standby’ mode after 15 minutes of user inactivity. This is done by sending a request to enter the link in Bluetooth ‘sniff’ mode with ‘sniff interval’ 0.5 sec. After the link enters the ‘Standby’ mode, the mobile can still receive traffic from the rest of the network, but the AP reduces the traffic reaching it by performing ARP proxying on its behalf. After 15 more minutes of user inactivity, the phone decides to keep the link in the ‘Standby’ mode, but increase the power savings by requesting a Bluetooth ‘sniff’ mode with ‘sniff interval’ 1.5 sec. If Bob resumed some activity at this point, the mobile would send a request to cancel the Bluetooth ‘sniff’ mode and it would get back to ‘Active’ mode, without much perceived delay. However, Bob has completely forgotten about his phone. Eventually, after 30 more minutes of inactivity the phone tears down the connection and turns its Bluetooth interface OFF.

IV. THE HOME NETWORK ARCHITECTURE

The DLNA home networking architecture is based on technologies defined by the IEEE 802 committee. Currently, DLNA [6] defines only three link-level technologies: 802.3, 802.11 and Bluetooth with the PAN profile [12].

Figure 1 shows an example connectivity model in a DLNA network. Mobile Handheld Devices (MHD) and Home Network Devices (HND) are essentially similar with respect to applications and network-level connectivity. The main

differences are in their support of possible different media formats and link-level bearers. In particular, MHDs are allowed to support Bluetooth in addition to 802.3 and 802.11. In the case of Bluetooth, an additional Bluetooth-Ethernet or Bluetooth-802.11 bridge is required. This functionality is provided by the M-NCF as shown in **Figure 1**.

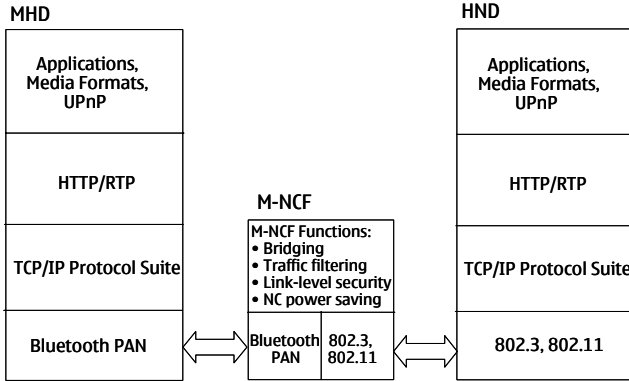


Figure 1: Depiction of an M-NCF bridging the network connectivity gap between MHD and HND devices.

Besides link-level connectivity, mobile devices have in general different requirements than fixed devices with respect to security and power saving. For instance, different requirements in the area of power saving may be due to the fact that most mobile devices are battery operated, while in the area of security to the fact that mobile devices may belong to visitors who only need to be given temporary access to the home network. In order to reflect these different requirements, the M-NCF may have additional mobile-specific functionality in addition to bridging, as shown in **Figure 1**. These features are built on top of the standardized link-level mechanisms.

Finally, it is noted that it is not mandatory for MHDs to attach to the home network via an M-NCF. They can connect directly through Ethernet cables or off-the-self AP, provided they support the necessary link-level bearer. However, connecting through an M-NCF, if available, allows MHDs to benefit from the additional mobile-specific functionality.

V. THE NC-PS MECHANISM

A. Overview

The NC-PS mechanism we propose describes how MHDs and M-NCFs collaborate to put the link between them in different Network Connectivity Power Saving (NC-PS) modes to reduce power consumption. The NC-PS modes are abstract power-saving modes of the connection between an MHD and an M-NCF and are defined as viewed from the IP-layer and above. The proposed NC-PS mechanism exposes a bearer-independent interface to applications, agents and other higher-layer entities and translates these abstract NC-PS modes to the appropriate native low-power states of the wireless bearer used. The underlying link-layer power-saving states depend on the specific radio bearer (e.g. Bluetooth, 802.11, UWB) and

are mapped accordingly to the NC-PS modes by the NC-PS mechanism. This is depicted in **Figure 2**.

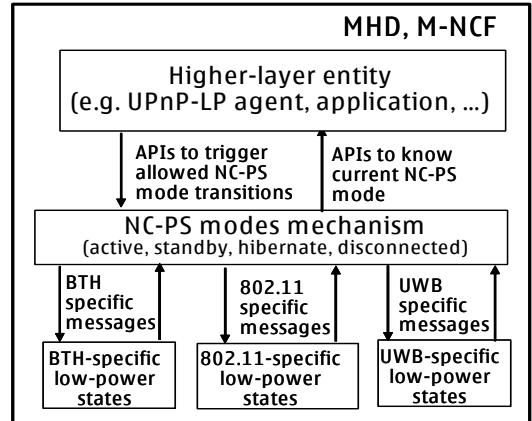


Figure 2: Bearer-independent NC-PS modes.

The alternative would be to expose bearer-dependent NC-PS modes to higher-layer entities, as depicted in **Figure 3**. We do not favor this approach because it would expose all the bearer-specific details and complexities to application developers and would require different application implementations to account for each specific bearer. The proposed approach puts this burden to the device manufacturers who implement the proposed NC-PS mechanism in their devices.

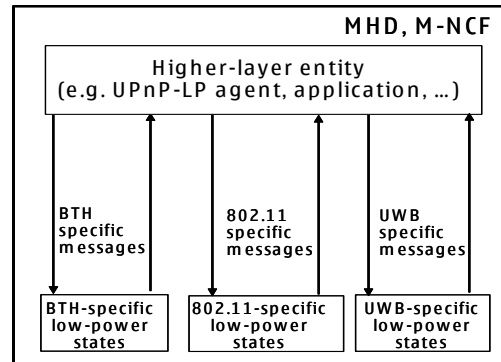


Figure 3: Bearer-dependent NC-PS modes.

The MHD and M-NCF exchange messages and coordinate to transition the connection between them in one of the NC-PS modes. However, one of our design goals was to avoid introducing any new protocols between the MHD and the M-NCF. Therefore, the proposed NC-PS mechanism relies on existing messages used by the link-level protocols to decide what is the desired NC-PS mode transition. The exact way to achieve this task is wireless-bearer specific, but the concept is the same for all. Wireless interfaces expose a Host Controller Interface (HCI) through which the host device can request the link to enter a specific low-power state. Once a higher-layer entity (e.g. an application, UPnP agent) on the requesting host side requests a transition to another NC-PS mode, the NC-PS mechanism uses the HCI to request a transition to the

corresponding bearer-specific low-power state. The NC-PS mechanism on the receiving host side, receives the bearer link-level message, interprets it as a request to transition to the corresponding NC-PS mode and responds based on whether this is an allowed transition or not.

B. Definition of NC-PS Modes

The proposed NC-PS mechanism² defines four abstract modes of the connection between an MHD and an M-NCF:

- **Active:** the radio is in the active mode. The MHD has full IP connectivity and can communicate in full speed. MHD and M-NCF communicate actively.
- **Standby:** the radio is in a power-saving state maintaining synchronization. The MHD and M-NCF keep full-state of their connection. The overall effect as seen by the network and higher-layer entities is a “congested”, slower link, but the MHD has full IP connectivity while in this mode. The MHD must reestablish its UPnP or other higher-layer network state upon becoming active again because timeouts may occur depending on the selected parameters of the underlying bearer power-saving state.
- **Hibernate:** the radio is in a deep-sleep state. UPnP and other higher-layer network state may be lost because the MHD is not responsive and timeouts occur, so the MHD must reestablish this state upon becoming active again. The MHD cannot exchange IP traffic, but the M-NCF and MHD ensure that some connectivity state is maintained (e.g. the IP address of the MHD³, its multicast group membership) to minimize network disruptions when the MHD becomes active again. Thus, the wake-up process is in general faster than establishing a brand new connection.
- **Disconnected:** the radio is off. No state is kept in the MHD and M-NCF to restore the connection. A new connection establishment process must be repeated.

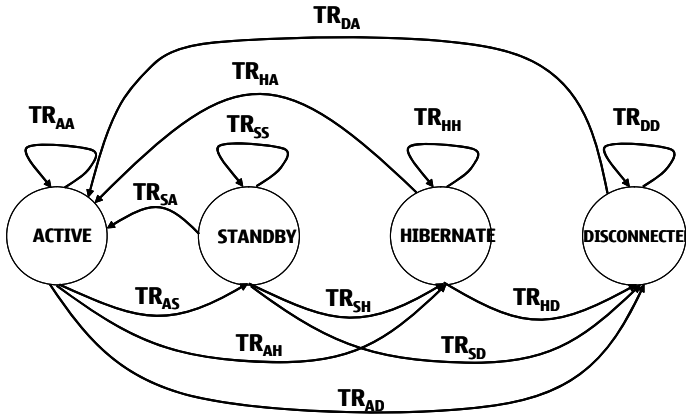


Figure 4: NC-PS mode transition diagram.

² Note that the actual DLNA NC-PS mechanism adopted in [6] defines only three of these modes: ‘Active’, ‘Standby’ and ‘Disconnected’.

³ To maintain the IP address of the MHD, the M-NCF needs to perform ARP proxying on behalf of the MHD to defend its IP address in the case of autoconfiguration. On the other hand, if the MHD has obtained its IP address through DHCP, then it knows when its lease expires and puts the link to the ‘Active’ mode to renew its lease.

C. NC-PS Mode Transitions

There is a fundamental asymmetry between the M-NCF and the MHD. On one hand, the M-NCF is a powered device and, therefore, it can always be active and afford some more power-intensive operations. On the other hand, the MHD is usually a battery-operated device and, therefore, as the more constrained side it should be the one that has more control in deciding when to put the link between them in a specific NC-PS mode. The M-NCF needs to adapt its behavior to accommodate the requests of the MHD. This principle is reflected on the definition of NC-PS mode transitions in **Figure 4** and explained below:

- **TR_{AS}** -Transition from Active to Standby: The MHD decides when this transition happens and the M-NCF must agree. The trigger is left undefined. It is up to MHD manufacturers, inactivity timers, higher layer entities (e.g. UPnP agents, applications).
- **TR_{SH}** -Transition from Standby to Hibernate: The MHD decides when this transition happens and the M-NCF must agree. The trigger is left undefined. It is up to manufacturers, timers, higher layer entities.
- **TR_{HD}** -Transition from Hibernate to Disconnected: Since in Hibernate there is no active link between the MHD and M-NCF, any of the two sides may decide at any time to declare the link Disconnected. A maximum timer must be agreed, after which both sides will stop any activity related to maintaining state. If only one side decides to declare the link Disconnected, the other will not know immediately. Eventually it will try to connect to the departed end in an effort to transition to the active state (TR_{HA}) and it will fail. That side will then also declare the link Disconnected.
- **TR_{AH}** -Transition from Active to Hibernate: The MHD decides when this transition happens and the M-NCF must agree. The trigger is left undefined. It is up to manufacturers, timers, higher layer entities.
- **TR_{AD}, TR_{SD}** -Trans. from Active/Standby to Disconnected: Any of the MHD and M-NCF may decide at any time to disconnect. The trigger is left undefined, e.g. a user action.
- **TR_{SA}** -Transition from Standby to Active: The MHD decides when this transition happens and the M-NCF must agree. The trigger is left undefined. It is up to MHD manufacturers, timers, higher layer entities.
- **TR_{HA}** -Transition from Hibernate to Active: Since in Hibernate there is no active link between the MHD and M-NCF, any of the two sides may decide to bring the link to the Active mode: the MHD because of an application or user action and the M-NCF because of incoming traffic for the MHD. The side that wants to do this, needs to reestablish an active link. The trigger on the MHD side is left undefined. It is up to MHD manufacturers, inactivity timers, higher layers, applications. The trigger on the M-NCF is unicast traffic with destination to the MHD. Additional triggers for the M-NCF side could be specified.

- **TR_{DA}** -Transition from Disconnected to Active: this is how a new connection is established. Usually, the MHD decides when this transition happens; however, it is possible that the M-NCF is configured to initiate it, in order to automate the task of connecting to the home network. The trigger is left undefined, usually based on user or application action.
- **TR_{AA},TR_{SS},TR_{HH},TR_{DD}** -Transition to the same NC-PS mode: involves timers (e.g. staying a minimum time).

D. Dynamic Traffic Reduction Operations

Reducing control traffic flowing between the MHD and M-NCF results in power savings, because the link between them can stay in a lower power state for longer periods of time. To reduce the traffic that reaches the MHD, the M-NCF may implement filtering and other control traffic reduction operations on behalf of the MHD. Examples include:

- **UPnP multicast filtering:** the M-NCF filters incoming multicast UPnP control traffic towards the MHD, e.g. device announcements and search queries.
- **ARP proxying:** the M-NCF acts as an ARP proxy on behalf of the MHD and responds to ARP queries.

Some of these traffic reduction operations (e.g. UPnP multicast filtering) may impact the functionality available to the MHD. Also, different traffic reduction operations reduce the traffic flowing by a different amount. Therefore, the set of traffic reduction operations the M-NCF performs on behalf of the MHD should depend on the NC-PS mode the link is in. The proposed dynamic behavior of the M-NCF is as follows:

- **Active:** the M-NCF performs no traffic reduction operations on behalf of the MHD.
- **Standby:** the M-NCF performs proxying and filtering operations on behalf of the MHD for traffic events occurring frequently (e.g. ARP proxying).
- **Hibernate:** the M-NCF performs any operations defined in the Standby mode, as well as additional operations for less frequent events (e.g. UPnP multicast filtering).
- **Disconnected:** the M-NCF performs no traffic reduction operations on behalf of the MHD.

E. NC-PS Mapping to Bluetooth

The abstract NC-PS modes defined in Section V.B have different mappings for each underlying wireless bearer. For Bluetooth, we propose the following mapping:

- **Active:** this NC-PS mode is mapped to the ‘active’ Bluetooth state. An active BNEP/L2CAP/ACL link exists between MHD and M-NCF. No power savings in place.
- **Standby:** this NC-PS mode is mapped to the ‘sniff’ Bluetooth state. A BNEP/L2CAP/ACL link exists between the MHD and M-NCF. Alternatively, the link could periodically enter the ‘hold’ state. This achieves more power savings than ‘sniff’, but would require a more complex signaling scheme.
- **Hibernate:** this NC-PS mode is mapped to the ‘park’

Bluetooth state. No BNEP/L2CAP/ACL link exists between the MHD and M-NCF. In addition, the MHD and M-NCF perform operations to maintain the IP address of the MHD as described earlier. Alternatively, this mode could be mapped to the Bluetooth link being torn down, but with both the MHD and the M-NCF performing periodic ‘page scanning’ and maintaining the Bluetooth clock information and MAC address of the other side. This would allow any of the two to ‘page’ the other side and re-establish the Bluetooth link in a fraction of a second, as opposed to the several seconds required to start a new connection from the Disconnected mode.

- **Disconnected:** this NC-PS mode is mapped to a disconnected Bluetooth link. The MHD and M-NCF perform no operation to maintain any state of the Bluetooth connection between them.

VI. CONCLUSIONS

In this paper, we presented a network connectivity power saving mechanism for mobile devices in DLNA home networks. The proposed mechanism exposes a bearer-independent interface that allows higher-level entities, e.g. UPnP low-power agents, to take advantage of the link-level low-power support without requiring bearer-dependent implementations. Finally, we presented a mapping of the abstract NC-PS modes for Bluetooth.

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