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SERVICE CATEGORY SYSTEM IN LOW-POWER AND LOSSY NETWORKS

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ABSTRACT

Presented herein are novel techniques to resolve cache capacity issues in Low-Power and Lossy Networks (LLNs) by utilizing border router edge computing. Following deployment of a network, such as an information-centric networking (ICN) network, a border router will generate a bitmap for all support services through negotiations with a cloud service (CS) and low-power devices. The border router will then cache data that satisfies specific service criteria for low-power devices that have registered for such data. The border router will further publish the service bitmap to a sleep proxy. A given low-power device can periodically examine the service bitmap via beacons to determine whether there may be any service(s) in which it is interested and, if so, respond to the border router.

DETAILED DESCRIPTION

As web caching technology has made great achievement to improve the experience for a site's visitors, efficient caching becomes increasingly attractive to address issues in other technology areas. Addressing well-known challenges for the Internet, information-centric networking (ICN) yields a steady improvement of network performance and caching efficiency over diverse operating environments. Many novel algorithms have been proposed to enable ICN caching, many of which rely on collaborative principles that aim to replace the existing end-to-end Internet model with a content request/response model. The in-network caching of the ICN networking model can effectively accelerate the transmission of massive data in the Internet of Things (IoT) and reduce the delay of data response.

Caching mechanisms have been deeply researched for the Institute of Electrical and Electronics Engineers (IEEE) 802.11 specification with regard to power management in which an access point (AP) maintains a cached buffer via a bitmap and broadcasts the bitmap in a beacon frame. Once a client receives the beacon, the client can retrieve the buffered data utilizing a Power Save Polling (PS-POLL) frame.

With regard to LLNs (e.g. IEEE 802.15.4g and 1901.2), low-power embedded networking devices can be used in a variety of deployments, such as an smart grid advanced metering infrastructure (AMI), home and building automation, wireless sensor networks (WSN), and the newly proposed concept of Industry-4.0. The Wireless Smart Utility Networks (Wi-SUN) alliance promotes interoperable wireless standards-based solutions for the Internet of Things. However, the ICN and PS-POLL mechanisms are not suitable in LLNs due to storage and computing limitations for low-power embedded networking devices.

In LLNs, devices communicate using low data rate links over a physical medium that can be strongly affected by environmental conditions that change over time. For such networks, thousands of devices can be connected hop-by-hop and can support various traffic flows, such as point-to-point, point-to-multipoint, and multipoint-to-point utilizing Internet Protocol (IP) version 6 (IPv6) Routing Protocols for LLNs (RPL) standardized by the Internet Engineering Task Force (IETF) Routing over Low-power and Lossy Network (ROLL) working group. Issues surrounding high-loss transmissions and multiple children prevent distributed caching mechanisms from being deployed in LLNs.

For low-power devices, battery life can be more important than communication rate. Thus, sleep intervals for low-power devices may be as long as several days in some cases. To save energy consumption, such low-power devices will sleep when not in use and wake up occasionally when there is a request expected to be received. Typically, a wake on demand method is used to wake up sleeping devices upon the obtaining such a request.

A parent of energy-constrained devices (also referred to as a 'sleep proxy') is typically responsible for helping a child node complete security authentication and associate into the network. In most use cases, the sleep proxy will cache packet(s) for sleeping devices, however, limited computing and memory for such sleep proxies can result in limit cache capacity, which is not satisfactory. Accordingly, new solutions to improve cache efficiency are needed.

Edge computing has brought various benefits to the Internet of Things, such as enabling reduced latency, lower costs, and local data storage. This proposal provides a novel technique to resolve cache capacity issued for LLNs by utilizing border router edge computing. Figure 1, below, illustrates example interactions that facilitate in-network caching for an ICN networking environment in accordance with the techniques of this proposal.

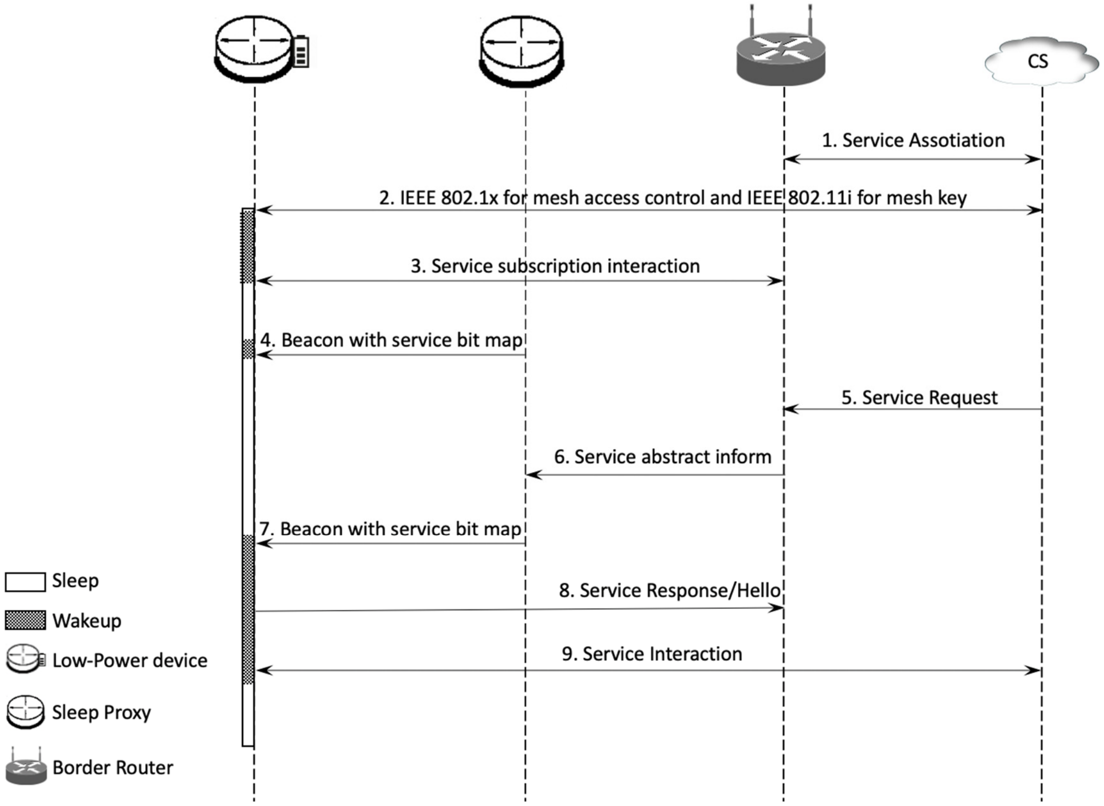

Figure 1: Example Interactions to Facilitate In-network Caching

With reference to Figure 1, following deployment, a border router (BR) will generate a bitmap for all supported services through negotiations with a CS and low-power devices. Following bitmap generation, the border router will cache data that satisfies specific service criteria for low-power devices that have registered to receive such data. The border router will further publish the service bitmap to a sleep proxy. A given low-power device can periodically examine the service bitmap via beacons to determine whether there may be any service(s) in which it is interested and, if so, respond to the border router.

As compared to the PS-POLL mechanism, the sleep proxy only needs to cache the service bitmap obtained from the border router. If a sleeping node is interested in the service, it can directly communicate with the border router or respond to cloud applications via the cloud service. Typically, a CS can provide per-device authentication, built-in device management, and scaled provisioning.

The border router will play a central role to maintain the caching and distributing process. The LLN low-power devices will use IEEE 802.1x for mesh access control and IEEE 802.11i for mesh key management to access the network, and then register to cloud management (CM).

Consider various broad operational phases with reference to Figure 1. In a first phase of operations, (phase 1) the CM can negotiate with the border router in order to download corresponding configuration information that may help the border router rapidly filter out services for the LLN low-power devices. At the same time, a valid bitmap bit that identifies the services that are to be subscribed is sent to the low-power devices (phase 3). The low-power devices can sleep and periodically wake up to examine the service bitmap in beacon from the sleep proxy (phase 4 and phase 7).

Such low-power battery devices can be characterized as having a limited lifetime, which indicates that the sleep mode can benefit the cost of production. In the sleep mode, a device can turn off the operational amplifier of its Radio Frequency (RF) circuitry and switch its microcontroller (MCU) to sleep. Similarly, signal monitoring saves more energy than transmission, so it is not necessary for devices to respond to unsubscribed services that may be identified in the bitmap, which can be carried via synchronization mechanisms with low-power devices. Thus, the sleep proxy should be a parent node configured with a power supply.

If a low-power device is interested in one service identified in the bitmap, it can send a 'Hello' response to the border router to retrieve detail information regarding the service (phase 8) and then finish the interaction with the border router and the CS (phase 9).

Although the techniques of this proposal provide for assigning the sleep proxy as the parent, the sleep proxy does not perform the caching. Rather, the cached buffer can be located in a cloud/fog or border router that plays a central role to maintain the caching and distributing process. During operation, the LLN low-power devices can subscribe to interested services, which can be divided into multiple on-demand categories by the border router. Thereafter, the sleep proxy can update the service bitmap from border router and broadcast the service bitmap to all the children via the border router. If the bitmap indicates that an interested service for a given low-power device is active, the device can actively provide a service response to the border router. Thus, techniques herein may provide for the ability for proxy parents to handle more packets and achieve higher performance in comparison to current deployments.

Regarding transmissions for the border router (or an AP), the border router will not need the time-slot for transmissions to a destination device, but rather waits for the destination's response to the beacon. Because the bitmap of service categories is directly transmitted to the sleep proxy of a destination and is broadcast via the sync beacon by the border router, the LLN devices can respond according to the bitmap, which provides a better communication mechanism for low power devices to remain asleep for long periods.

ICN services can be divided into multiple categories in LLNs, such as common services, on-call services, and entrepot services. Such division of services may provide for the ability to handle many different services/service categories based on configuration of the border router. For example, each service category may have different working modes needed to satisfy various LLN requirements. The border router can form a bitmap of service state and transmit it to the sleep proxy over multi-hops. The LLN devices can respond differently according to the categories.

Considering that the border router of this proposal is to handle many of the interactions between the CS and LLN devices, techniques of this proposal further provide for the introduction of a new ICN service feature into the data plane. The ICN service in data plane can be used to detect pre-defined services and punt the data to control layer to be handled by the application layer.

Thus, in addition to providing networking routing functions for low-power nodes, the border router can also provide application-level services. By providing uniform and consistent hosting capabilities for fog applications reductions can be realized for data, filtering, and aggregation at a source in order to facilitate real time decisions at the edge border router. Figure 2, below, is a system block diagram illustrating example details associated with the data plane and control plane of border router.

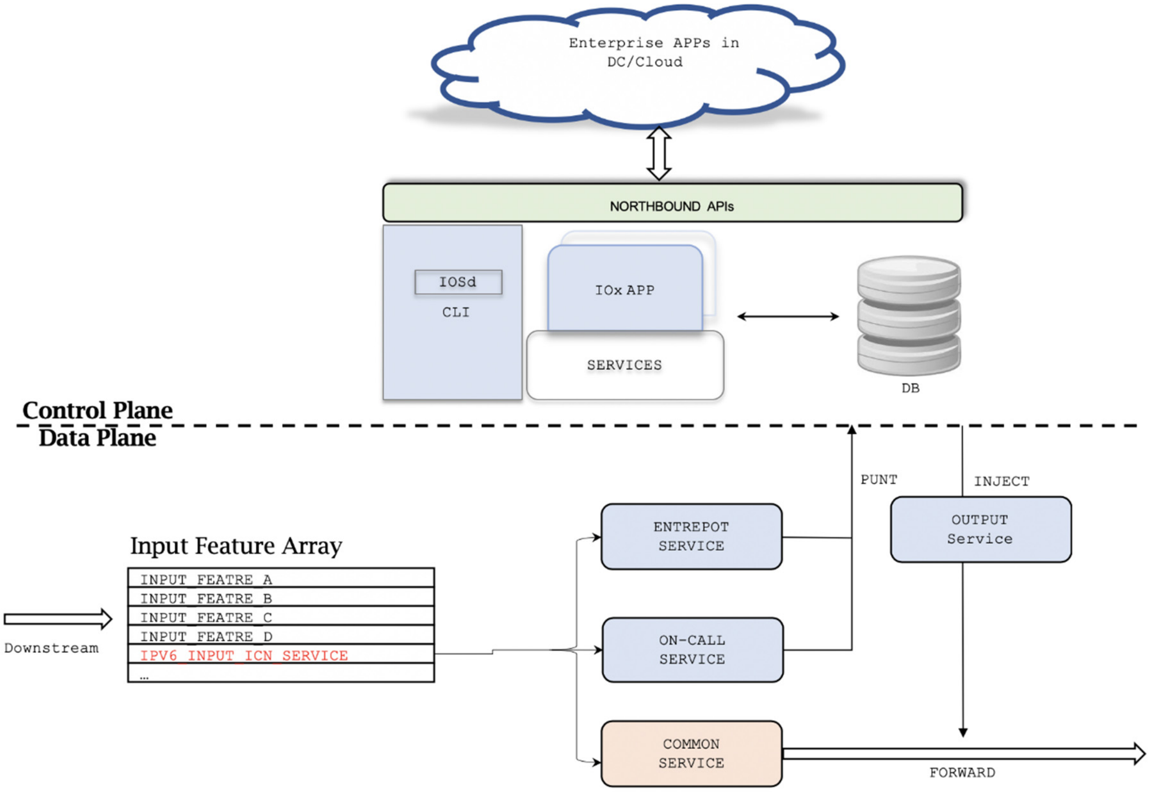

Figure 2: Border Router Control and Data Plane Details

During operation, the process of iteratively walking through feature invocation for an input feature array may proceed from one feature to the next without changing the flow of control. The ICN service feature can retrieve configuration details from the control plane and punt pre-registered service data to the control plane. Operating system (OS) applications can store data to a local or remote database (DB) based on the type of ICN services and can also choose any items to discard in order to make room for the new data when the cache is full. Upon receiving a Hello response from a message owner, the border router will respond with a corresponding command (e.g., such as a cloud call) or data (e.g., such as a firmware upgrade) and update the bitmap.

The northbound Application Programming Interfaces (APIs) can be utilized to create communications between the cloud and fog in order to maintain the ICN service (phase 1 in Figure 2). If cloud applications need to update or query a certain service, the northbound APIs can handle such communications. Similarly, the border router can utilize the northbound APs to notify the cloud for different cases.

Recall, ICN services can be divided into three categories: common services, on-call services, and entrepot services. For common mode services, data can be forwarded directly, which means that the data can be cached on the sleep proxy rather than the border router. On-call and entrepot mode services will involve punting data to the control plane in order for the data to be handled by OS applications. On-call mode services can be used to notify a low-power device to interact with the cloud and entrepot mode services can be used to relay data directly to a low-power device. Thus, in this architecture, the sleep proxy is to have the ability to cache a few data packets and also broadcast a bitmap that is updated from the border router.

In some instances, reserved services defined in the bitmap, as illustrated in Figure 3 below, can include firmware upgrade services, configuration download services, etc. In some instances, user defined services can also be configured to access different types of applications.

```
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   Association ID   | Reserved Services | User Defined Services  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 3: Example Bitmap

In summary, techniques are provided herein to resolve cache capacity issues in LLNs by utilizing various border router edge computing processes.