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Supplement 35

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SERIES Y: GLOBAL INFORMATION INFRASTRUCTURE, INTERNET PROTOCOL ASPECTS AND NEXT-GENERATION NETWORKS, INTERNET OF THINGS AND SMART CITIES

ITU-T Y.3033 – Data aware networking – Scenarios and use cases

ITU-T Y-series Recommendations – Supplement 35

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Supplement 35 to ITU-T Y-series Recommendations

ITU-T Y.3033 – Data aware networking – Scenarios and use cases

Summary

Supplement 35 to ITU-T Y-series Recommendations applies to Recommendation ITU-T Y.3033. The Supplement present a set of service scenarios and use cases supported by data aware networking (DAN) including: 1) content dissemination; 2) sensor networking; 3) vehicular networking; 4) automated driving; 5) networking in a disaster area; 6) advanced metering infrastructure in a smart grid; 7) proactive video caching; 8) in-network data processing; 9) multihoming; and 10) traffic engineering. It provides informative illustrations and descriptions of how DAN can be designed, deployed and operated to support DAN services. In addition, the benefits of data aware networks to the scenarios and use cases, as well as several migration paths from current networks to data aware networks, are elaborated.

History

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1 Scope

The scope of this Supplement to [ITU-T Y.3033] includes the following items:

- informative illustrations and descriptions of service scenarios and use cases supported by data aware networking;
- elaboration of the benefits of data aware networks to the scenarios and use cases, as well as several migration paths from current networks to data aware networks.

2 References

[ITU-T Y.3001]	Recommendation ITU-T Y.3001 (2011), *Future networks: Objectives and design goals.*
[ITU-T Y.3033]	Recommendation ITU-T Y.3033 (2014), *Framework of data aware networking for future networks.*

3 Definitions

3.1 Terms defined elsewhere

This Supplement uses the following terms defined elsewhere:

3.1.1 data object [ITU-T Y.3033]: An individually identifiable unit of information created by individuals, institutions and technology to benefit audiences in contexts that they value.

3.1.2 future network (FN) [ITU-T Y.3001]: A network able to provide services, capabilities, and facilities difficult to provide using existing network technologies. A future network is either:

a) A new component network or an enhanced version of an existing one, or

b) A heterogeneous collection of new component networks or of new and existing component networks that is operated as a single network.

3.1.3 identifier [b-ITU-T Y.2091]: An identifier is a series of digits, characters and symbols or any other form of data used to identify subscriber(s), user(s), network element(s), function(s), network entity(ies) providing services/applications, or other entities (e.g., physical or logical objects). Identifiers can be used for registration or authorization. They can be either public to all networks, shared between a limited number of networks or private to a specific network (private IDs are normally not disclosed to third parties).

3.1.4 name [b-ITU-T Y.2091]: A name is the identifier of an entity (e.g., subscriber, network element) that may be resolved/translated into an address.

3.1.5 service [b-ITU-T Z. Sup.1]: A set of functions and facilities offered to a user by a provider.

3.2 Terms defined in this Supplement

This Supplement defines the following terms:

3.2.1 named data object (NDO): A data object that is identifiable by a name.

NOTE – In this Supplement, NDOs include both what is not executable as a software program, and what is executable as a software program.

3.2.2 NDO-data: An NDO that is not executable as a software program (e.g., videos, text files and measurement data).

3.2.3 NDO-func: An NDO that is executable as a software program. NDO-func takes NDO-data as input and produces another set of NDO-data as output after processing.

4 Abbreviations and acronyms

This Supplement uses the following abbreviations and acronyms:

AMI Advanced Metering Infrastructure

CAN Controller Area Network

CDN Content Delivery Network

DAN Data Aware Networking

DPI Deep Packet Inspection

DSRC Dedicated Short Range Communication

FN Future Network

HTTP Hypertext Transfer Protocol

HTTPS Hypertext Transfer Protocol – Secure

ID Identifier

IoT Internet of Things

IP Internet Protocol

IrDA Infrared Data Association

ISP Internet Service Provider

LTE Long Term Evolution

NDN Named Data Networking

NDO Named Data Object

PC Personal Computer

QoS Quality of Service

SDN Software-Defined Networking

SNS Social Networking Services

TCP Transmission Control Protocol

TLS Transport Layer Security

VPN Virtual Private Network

WAN Wide Area Network

WAP Wireless Application Protocol

WLAN Wireless Local Area Network

5 Conventions

In this Supplement, there are no specific conventions.

6 Overview

[ITU-T Y.3001] defined the data access design goals of future networks (FNs) as the ability to deal with enormous amount of data efficiently in a distributed environment and to enable users to access desired data safely, easily, quickly and accurately, regardless of data location. This design goal was proposed in the form of a network architecture named data aware networking (DAN) in [ITU-T Y.3033].

The aim of this Supplement is to introduce the scenarios and use cases of DAN, which provides a technical context that is expected to be useful for discussions on architectural requirements of DAN in further documents to be developed, and also to clarify the roles and interactions of the various types of DAN entities for services delivered via DAN.

The set of the scenarios and use cases is not intended to be exhaustive, but sufficient enough to provide an understanding of DAN operation. Currently, this Supplement includes a set of use case scenarios: 1) content dissemination; 2) sensor networking; 3) vehicular networking; 4) automated driving; 5) networking in a disaster area; 6) advanced metering infrastructure (AMI) in a smart grid; 7) proactive video caching; 8) in-network data processing; 9) multihoming; and 10) traffic engineering. It may be updated as new use cases are identified as being helpful in understanding the operation of DAN or in deriving its architectural requirements.

7 Service scenarios

7.1 Content dissemination

This service scenario describes DAN as a cooperative caching architecture for efficient content dissemination. This service provides users with fast and reliable access by distributing content to ubiquitous caching points located close to users. Moreover, due to the context awareness of DAN, each caching point can easily adapt the content in terms of the given context from users, and serve it to them accordingly.

DAN can be deployed either by content distributors, e.g., content delivery networks (CDNs), or by network operators, e.g., internet service providers (ISPs). While content distributors aim to make a profit by providing delivery services for content providers, network operators deploy DAN mainly to reduce transit traffic or improve quality of service (QoS) for users.

For the distribution of content files, either the DAN operator actively pushes popular content to caching points to deal with some events, e.g., flash crowd, or contents can be passively cached at points along the downloading path while being pulled from the requester. Routing mechanisms in DAN are responsible for directing users' requests to appropriate caching points. The routing mechanisms also interact with the distribution mechanisms in order to keep content at caching points up-to-date.

Figure 7-1depicts a sample scenario for content dissemination service using DAN.

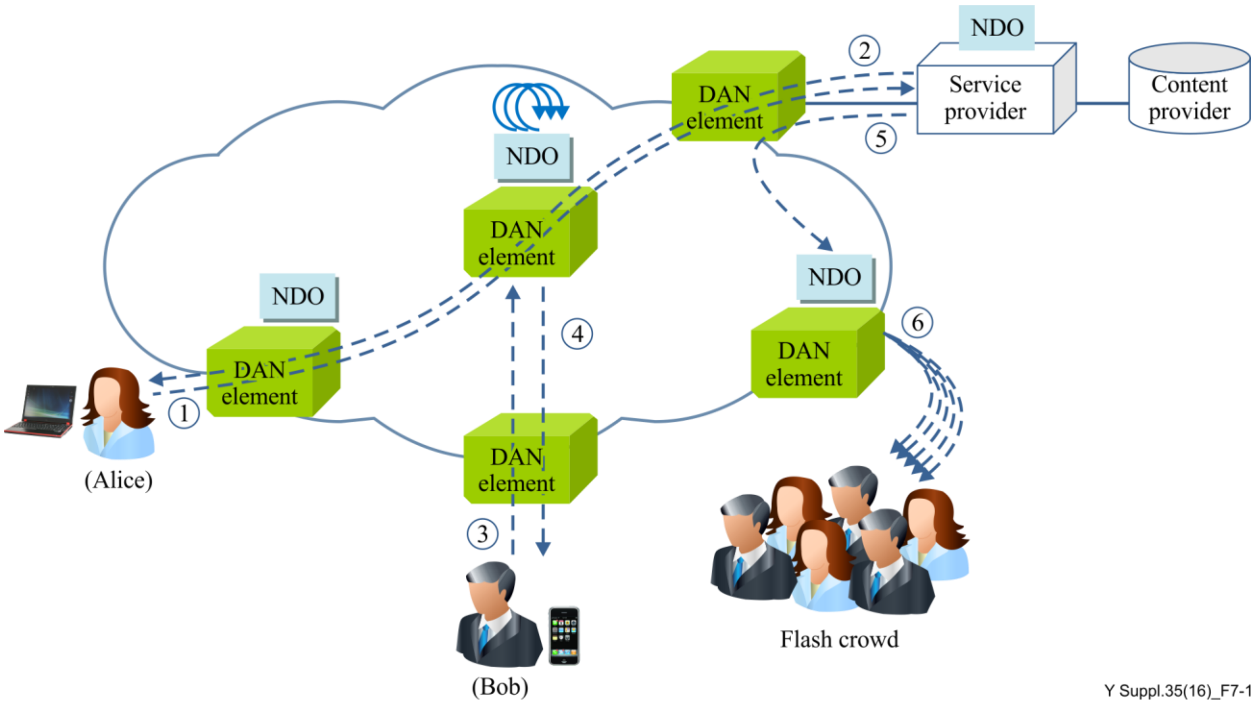

Figure 7-1 – Content dissemination using DAN

The operational procedures of the scenario are as follows:

1) Alice requests a named data object (NDO) from its service provider.

2) While the requested NDO is downloaded from the service provider to Alice, it can be stored on the selected DAN elements along the downloading path, e.g., a center node of all access points close to the end user.

3) Bob, with a mobile device, requests an NDO from the service provider. At this time, the request hits the cached NDO on the DAN element.

4) Thus, the NDO is directly served from the DAN element, not from the service provider. Moreover, the DAN element may process the NDO, so that its format fits the capability of Bob's mobile device.

5) The service provider detects a flash crowd and so actively pushes popular NDOs to a DAN element close to the flash crowd.

6) Requests from the flash crowd are directly served from the DAN element nearby.

Figure 7-2 is a procedural diagram of functions for a DAN content dissemination service.

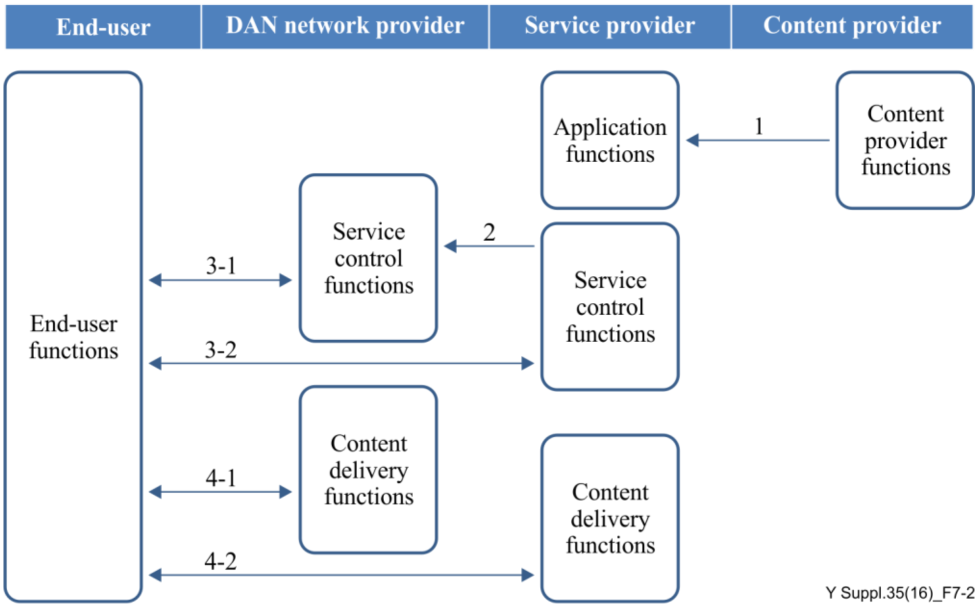

Figure 7-2 – Use case of content dissemination with DAN

1) The content provider provides the service provider with content including all relevant meta-data. Then, the service provider produces NDOs by naming the content based on their meta-data.

2) The service provider publishes the NDOs, which distributes routing information that leads toward the NDOs. Moreover, the service provider provides the DAN elements with its public key, which authorizes the DAN elements to serve the corresponding NDOs.

3) When an end user wants to access an NDO, if the NDO is available on the DAN elements, the request is sent to the DAN element close to the end user, which holds the requested NDO in its cache or storage (labelled (3-1) in Figure 7-2). Otherwise, the request is directly delivered to the service provider (3-2).

4) Either a DAN element (4-1) or the service provider (4-2) supplies the NDO to the end user. The NDO may be processed before being served to fit the capability of the device of the end user.

7.1.1 Benefits

Network operators have experienced an explosive increase in demand from mobile devices, especially those which download all forms of multimedia traffic from the network. Flash crowds triggered by mobile users make advance provisioning difficult for operators of networks. At the same time, mobile users tend to experience unexpected delays and disruption due to content retrieval from inappropriate locations and frequent handover.

Current CDN is based on an overlay solution provided by a small number of players, especially targeting for limited applications, e.g., mostly based on the hypertext transfer protocol (HTTP). The lack of interoperation among multiple CDN operators prevents scalable content dissemination in a coordinated manner, which makes content distribution inefficient. Moreover, context awareness is not a mandatory function for a CDN, unless an additional system component, such as deep packet inspection, is accommodated. Thus, CDN cannot deal with the flash crowd problem in an adaptive manner.

DAN extends the geographic distribution of contents by leveraging in-network caching, which is the first order mechanism of DAN for all types of applications. Due to the natively supported awareness feature of DAN, content name as well as its meta-data are visible to DAN elements, so that DAN can provide content dissemination service more adaptively in a coordinated manner compared to conventional CDNs.

7.2 Sensor networking

This service scenario involves sensor devices connected to a network and DAN elements collect sensor data generated from the sensor devices. Sensor devices can be either wired or wireless, connecting to the network using various wireless technologies. Sensor devices can be either fixed or mobile. They can be standalone devices or ones attached to other systems. Sensor data can be of any kind generated by sensor devices.

DAN elements can be located anywhere in the network, from gateway nodes close to the sensor device, edge nodes at the network edge or core nodes in backbone networks. DAN elements can be switch-based nodes that have integrated data switching functionality or server-based nodes that are attached to the network to process DAN traffic in an overlay manner. DAN elements collect sensor data and retain the data in their storages. They also optionally apply processing to the data, such as conversion of data format and aggregation of information. DAN elements then forward the data, if necessary, to the corresponding DAN element or servers. DAN elements can be deployed by a sensor data user, a sensor networking service provider or network operators.

Figure 7-3 depicts a scenario for sensor networking using DAN.

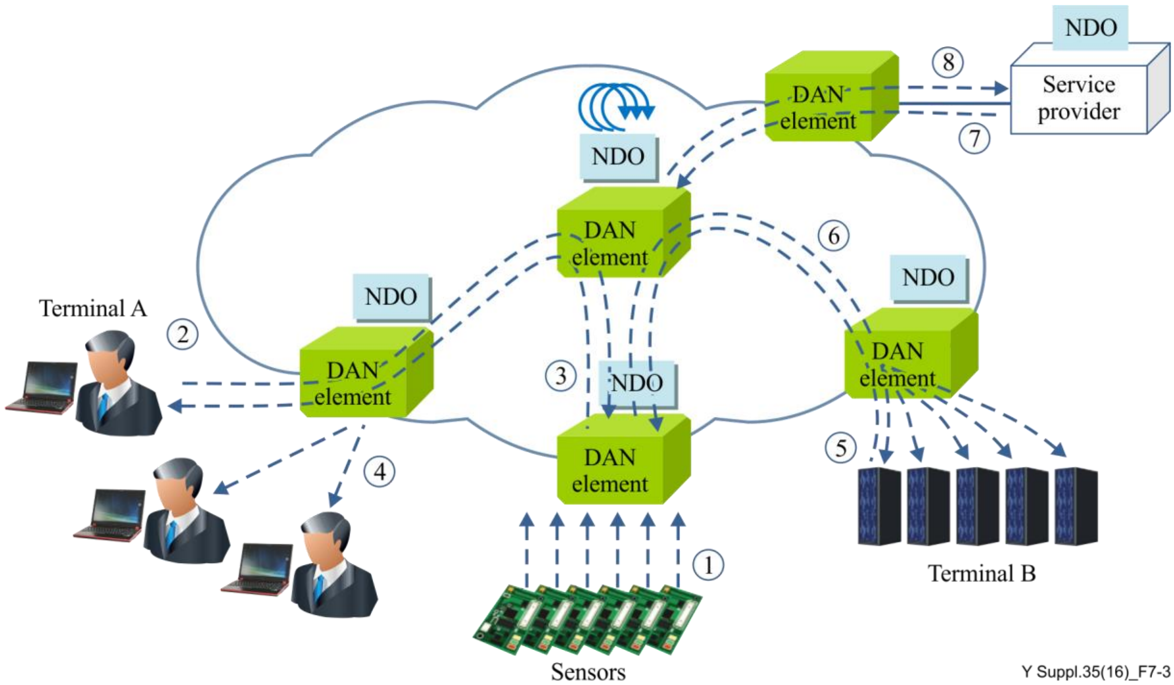

Figure 7-3 – Sensor networking using DAN

The operational procedures of the scenario are as follows:

1) Sensors generate sensor data and send them to the first hop DAN element. The DAN element stores the sensor data as NDOs and distributes routing information that leads towards the NDOs.

2) Terminal A (user PC) requests an NDO using its ID. The request is routed to the first hop DAN element from the sensors.

3) The NDO is transferred back to terminal A. The NDO is stored on selected DAN elements along the transferred path, e.g., close to terminal A.

4) Subsequently, other terminals that are connected to the same DAN element as terminal A request and retrieve the same NDO from the first hop DAN element from terminal A.

5) Terminal B (sensor processing server) and other terminals that are connected to the same DAN element subscribe to an NDO, and the first hop DAN element from terminal B distributes routing information that directs the request for the NDO towards itself.

6) NDOs stored on the first hop DAN element from the sensors are transferred to the first hop element from terminal B and they are sent to connecting terminals including terminal B by multicast.

7) The service provider requests the NDO from the first hop DAN element from the sensors. At this time, the request hits the cached NDO on the DAN element.

8) NDOs stored on the intermediate DAN elements are processed (e.g., aggregated and compressed) according to a preconfigured policy and the processed NDOs are sent to the service provider using a pre-set route.

Figure 7-4 is a procedural diagram of DAN functions for sensor networking service.

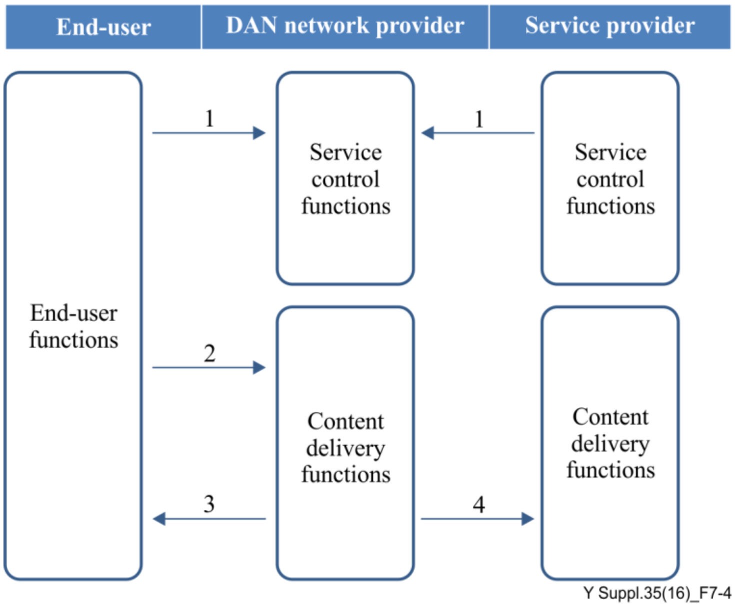

Figure 7-4 – Use case of sensor networking with DAN

1) The end user and service provider subscribe to NDOs. The service provider additionally specifies a processing policy (e.g., aggregation and compression) that should be applied to the subscribed NDOs.

2) The end user publishes the NDOs.

3) The DAN network provider transfers the NDOs to end users who subscribe to the NDOs.

4) The DAN network provider processes the NDOs based on the processing policy and transfers the processed NDO to the service provider.

7.2.1 Benefits

The user of sensor data benefits from DAN, due to its simple method of data uploading and access. The sensor device does not need to specify the final destination of the sensor data, but simply specifies the name or ID of the sensor data and sends it to a DAN element using broadcast, etc. The user of the sensor data also does not need to specify the location or address of the DAN element where the sensor data are stored, but simply specifies the name of the data. This greatly simplifies the design of sensor devices and applications regarding data communication.

The service provider or the network operator benefits from DAN due to its efficient mechanism for uploading sensor data. The data are collected at a DAN element close to the sensor device, which reduces transmission delay and uplink traffic. The sensor device needs to wait for a minimal transmission time to upload its sensor data. The sensor device also does not need to manage an end-to-end communication session to data consumers, which reduces the burden on the sensor device for data communication.

The service provider or the network operator also benefits from DAN, due to its simple management of mobility. The sensor device can be moved to another location without any reconfiguration at the DAN layer. The user can access sensor data without reconfiguration of location or address, which reduces sensor network management costs where sensor numbers are large.

7.3 Vehicular networking

This service scenario involves vehicles (such as automated cars and trains) that are connected to the network and DAN elements collecting vehicle-related data generated from in-vehicle devices. In-vehicle devices can be either a navigation system including smartphones attached to the vehicle or an embedded system such as on-board wireless system attached to a controller area network (CAN). Vehicle-related data include location information (e.g., current location, destination location), driving information (e.g., steering, velocity, acceleration, braking) or states information (e.g., fuel level, maintenance information).

Figure 7-5 depicts a sample scenario for vehicular networking using DAN.

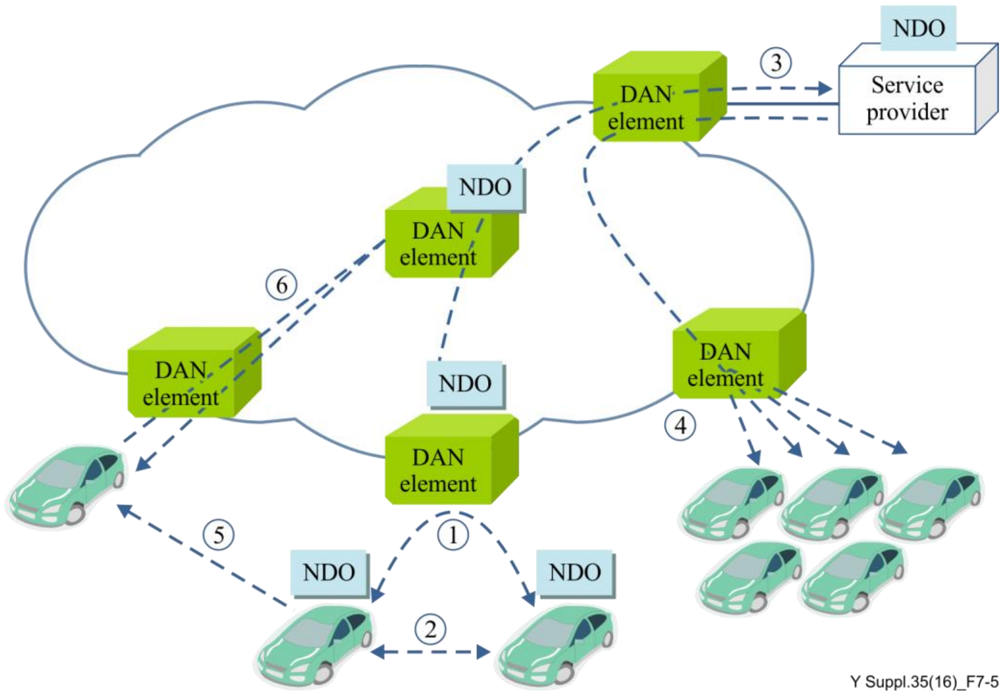

Figure 7-5 – Vehicular networking using DAN

The operational procedures of the scenario are as follows:

1) Vehicles share NDOs among themselves through the DAN element.

2) Vehicles share NDOs among themselves directly.

3) The DAN elements forward collected NDOs from vehicles to the service provider. The NDOs can be stored in selected DAN elements on the way to the service provider.

4) The service provider sends the NDOs to the first hop DAN element close to vehicles. The DAN element broadcasts the NDO to connected vehicles.

5) A vehicle moves to another DAN element while downloading an NDO.

6) The vehicle continues to download the rest of the NDO from the closest DAN element that holds the NDO in its cache.

Figure 7-6 is a procedural diagram of DAN functions for vehicular networking.

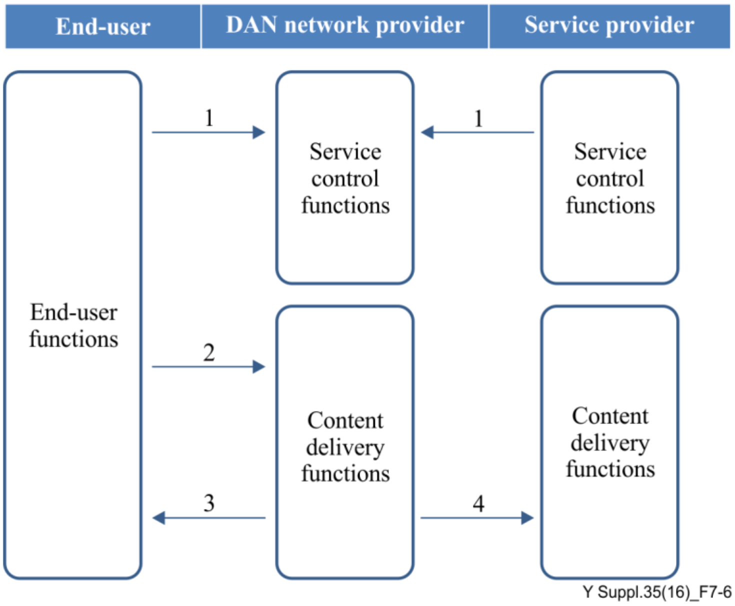

Figure 7-6 – Use case of vehicular networking with DAN

1) The end user and service provider subscribe to NDOs. The service provider additionally specifies a processing policy (e.g., aggregation and compression) that should be applied to the subscribed NDOs.

2) The end user publishes the NDOs.

3) The DAN network provider transfers the NDOs to end users who subscribe to the NDOs.

4) The DAN network provider processes the NDOs based on the processing policy and transfers the processed NDO to the service provider.

7.3.1 Benefits

A network operator can benefit from DAN in regards to simplified mobility management. The data are routed using their names that are independent of the location. DAN does not require tunnelling and binding processes that are necessary in location-based protocols, such as mobile IP. This may provide more simplified handover that is optimal for short range radio communication, such as wireless local area network (WLAN) and dedicated short range communication (DSRC).

A network operator can also benefit from DAN in regards to efficient data collection from in-vehicle devices. The data are collected at a DAN element close to the wireless base station, which reduces transmission delay and uplink traffic compared to the in-vehicle devices uploading data to the data center. The in-vehicle device needs to wait for a minimal transmission time and does not need to manage end-to-end communication sessions. This service scenario shows how DAN elements close to end users can provide edge computing services.

7.4 Automated driving

This service scenario describes DAN as a collaborative architecture to support seamless communication for automated driving. The automated driving scenario is associated with network-assisted driving for human drivers. Automated vehicles pull the NDOs they demand, e.g., position data, accident or traffic jam information, when they go on a road. The service provider pushes positional data or other NDOs to vehicles at specific positions (corresponding to different areas) of road via access points (APs) that act as DAN elements. As NDOs are used as interactive content, the service provider needs to guarantee low latency (less than a valid threshold value) for high QoS, in the case of automated driving.

To provide real-time mobility access, mobile nodes may have different identifiers assigned from a separate namespace, e.g., node name as shown in [b-López, 2016].

Figure 7-7 depicts a sample scenario for automated driving service with DAN.

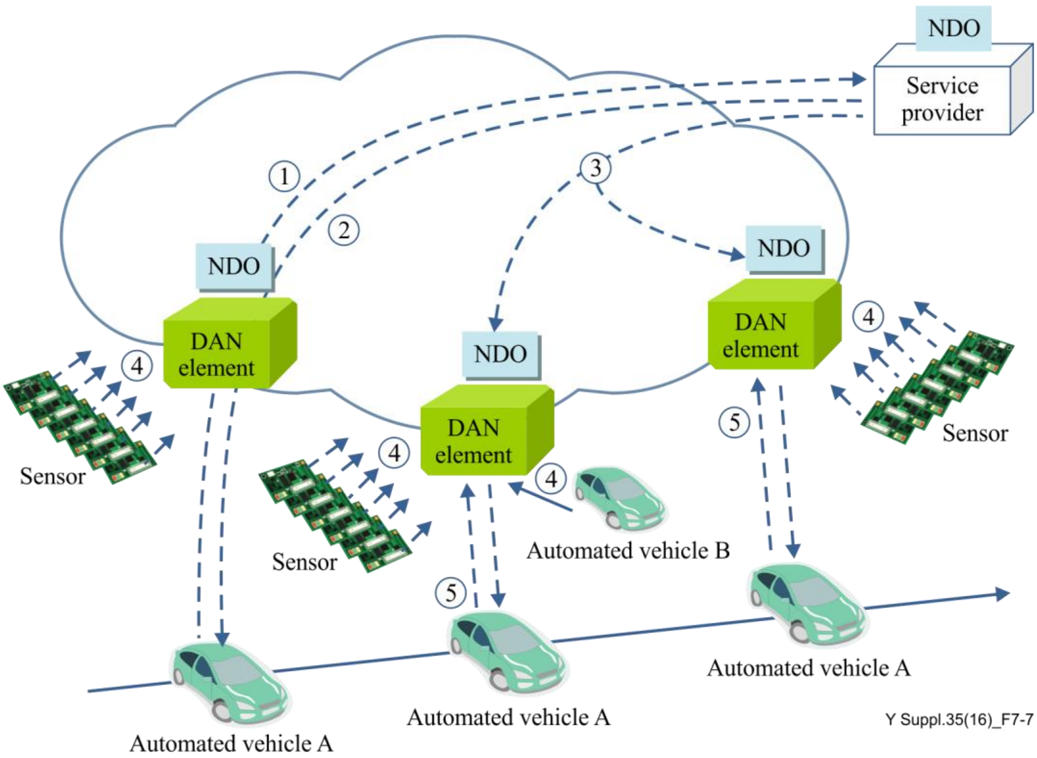

Figure 7-7 – Automated driving with DAN

The operational procedures of the scenario are as follows:

1) An automated driving end user requests a positional data or traffic NDO from the corresponding service provider. At the same time, the end user reports the expected route to the service provider for the automated driving support.

2) The end user receives the requested NDO via a DAN element (wireless application protocol (WAP)).

3) The service provider informs the DAN elements on the expected route of the end user where the automated vehicle is authenticated to get the data for automated driving.

4) The updated NDOs are pushed to the nearby DAN elements by sensors or newly pass-through in-vehicle devices to maintain the accuracy of current traffic data and support seamless retrieval of data with low latency for the automated driving end user. Even if the DAN network provider fails, e.g., due to disaster, the end user can still receive geographical and positional data, such as intersection information and hidden objects on the road, as well as GPS for navigation.

5) While the end user moves to the DAN elements on the path, the user is able to receive the NDOs required for automated driving.

Figure 7-8 is a procedural diagram of DAN functions for automated driving service.

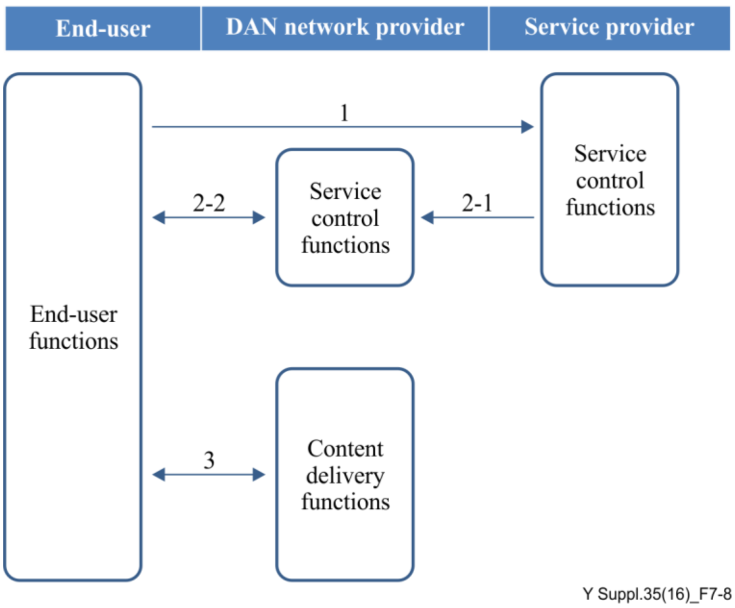

Figure 7-8 – Use case of automated driving with DAN

1) The end user sends the service provider a request for interactive data, e.g., position and traffic NDOs, together with an expected route for automated driving.

2) The service provider informs all related DAN elements about the arrival of the authenticated vehicle and requests interactive NDOs with the vehicle for its automated driving (labelled 2-1 in Figure 7-8). The service provider offers the DAN elements (WAPs) its public key, which authorizes the DAN elements to serve the requested NDOs.

3) Then the updated NDO is pushed to the DAN element from its connected sensors or newly pass through vehicles if some special events occur, e.g., an accident or traffic jam. In other words, updated NDOs may be uploaded by sensors or taken from new state information from in-vehicle devices close to the DAN elements. Therefore, the updated NDO is available in DAN elements for automated driving support (2-2).

4) The DAN element provides the end user with the desired NDO interactively when the end user passes through the respective DAN element on a road. The NDO may be processed before being served, in order to fit the capability of the end user's in-vehicle device.

7.4.1 Benefits

In order to detect hidden objects beyond a sightline, e.g., a child running around a corner or a car pulling out of an occluded driveway, an automated vehicle can communicate with static infrastructure, such as sensors on the road, which is connected to DAN elements (e.g., WAPs), or even with other vehicles in the vicinity. For vehicular ad-hoc networks used in current communication between vehicles, it is necessary to identify their locations based on the Internet protocol (IP). However, for efficient automated capability, the whole communication system should focus on accessing content (rather than a particular destination) that can be supported by DAN.

The user of automated driving can benefit from DAN due to its simple method of uploading and accessing an NDO via sensors. The automated vehicle only needs to specify the name or ID of the sensor data and send them to a connected DAN element, regardless of the final destination of the sensor data. The user of sensor data does not need to specify the location or address of the DAN elements. The service provider and network operator also benefit from DAN due to its efficient data collection. This mechanism can efficiently reduce transmission delay and simplify mobility management over ubiquitous DAN elements.

7.5 Networking in a disaster area

This service scenario describes DAN as a communication architecture which provides an efficient and resilient data dissemination in a disaster area, e.g., north eastern Japan (Tōhoku) hit by an earthquake and tsunami on 11 March 2011 [b-FG-DR&NRR].

A provider can directly disseminate emergency data to a particular person or group of people. In this case, consumers can express their interest in particular emergency data in advance so that DAN can deliver emergency data when they are available. A provider can directly disseminate emergency data to many and unspecified people regardless of any prior request for such a service.

A provider can push emergency data to the cache or storage of DAN elements and then DAN elements can indirectly deliver emergency data from their caches or storages to a particular person, a group of people or many and unspecified people in the network.

DAN elements have sufficient storage capacity and so they can hold emergency data for a long time. Provider(s) and consumer(s) can use the storage as intermediate devices to share any emergency data with others during a disaster period.

A DAN mobile element, e.g., carried by vehicles and rescuers, can deliver emergency data among fragmented networks. A fragmented network is one that is locally connected by wired or wireless links without any connections to a wide area network (WAN) service such as the Internet. A typical example is a cell covered by a base station isolated from the WAN.

Figure 7-9 depicts a sample scenario for networking in a disaster area.

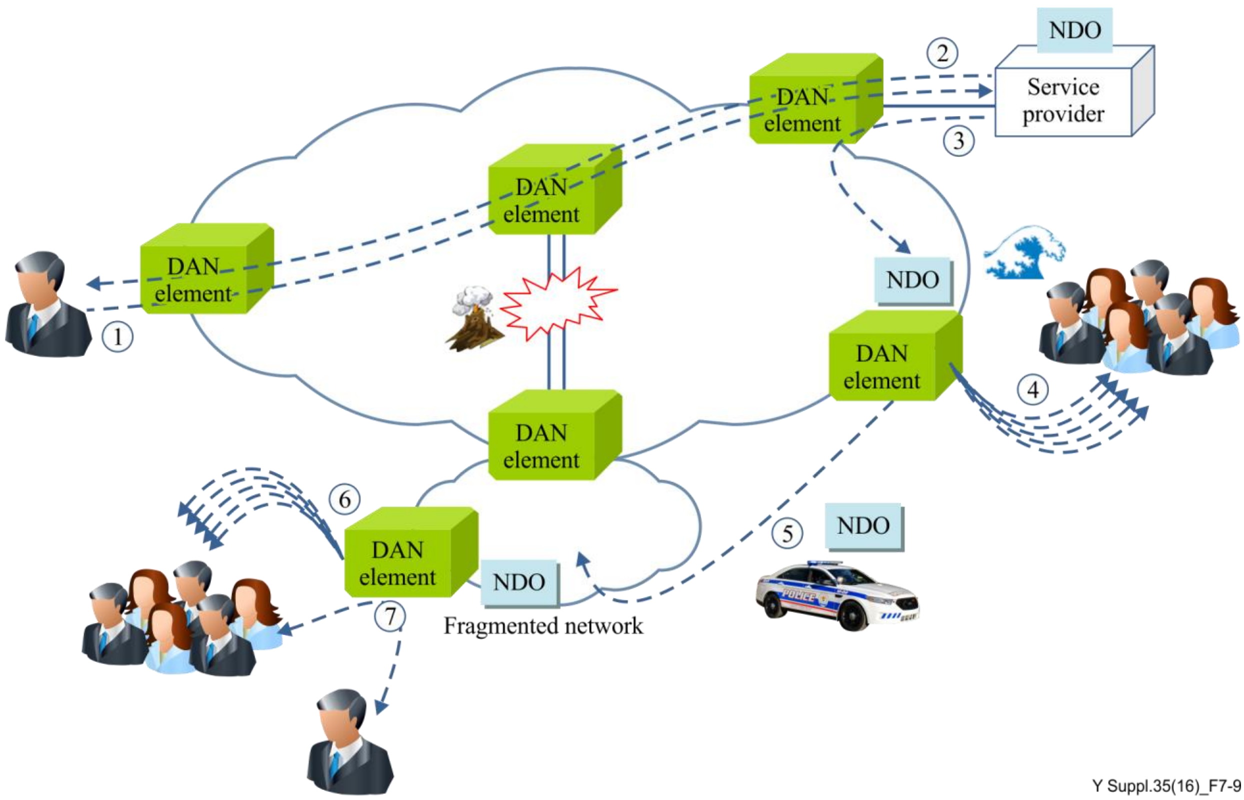

Figure 7-9 – Networking in a disaster area with DAN

The operational procedures of the scenario are as follows:

1) An end user subscribes to emergency data from the service provider.

2) The emergency data are pushed to the subscriber when they are available.

3) The service provider may push the emergency data to the DAN element close to the disaster area.

4) Then the DAN element informs many and unspecified people of the emergency situation by pushing the emergency data to them.

5) The DAN elements in a fragmented network may indirectly receive the emergency data, e.g., through a patrol car carrying the data from a non-disaster area.

6) The DAN elements deliver the data to many and unspecified people in the fragmented network.

7) Users in the fragmented network can share information with others through the DAN elements that have storage and processing capabilities.

Figure 7-10 is a procedural diagram of DAN functions for this scenario.

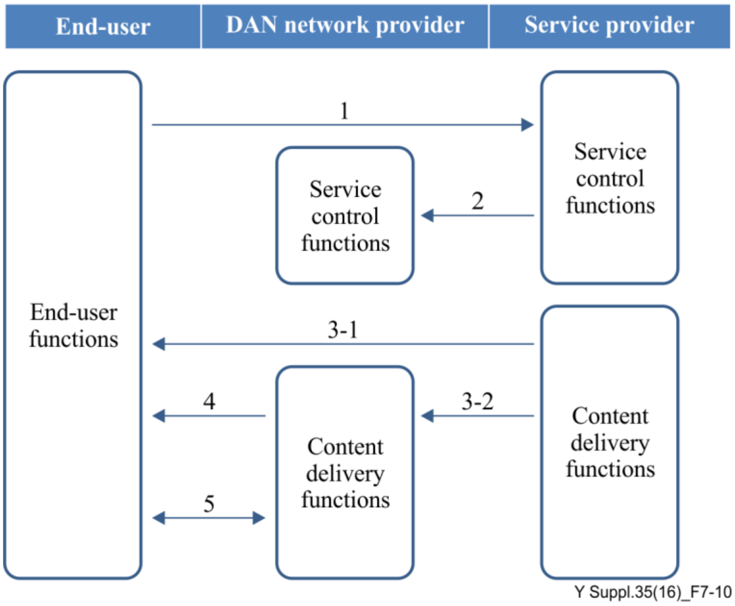

Figure 7-10 – Use case of networking in a disaster area with DAN

1) The end user subscribes to emergency data from the service provider.

2) The service provider configures the DAN network to push the emergency data to individual subscribers.

3) When the emergency data are available, the service provider pushes the emergency data to subscribers (labelled 3-1 in Figure 7-10), and to the cache or storage of DAN elements (3-2).

4) The DAN network pushes the emergency data to its non-subscribers to inform them of the emergency situation.

5) Isolated end users in a disaster area share disaster-related information with others through the DAN element.

7.5.1 Benefits

A provider can efficiently and resiliently disseminate emergency data in a disaster area due to the cache and forward function of DAN in which emergency data are sent to an intermediate DAN element where the data are kept (cached) first and then sent to the final destination or to another intermediate DAN element. The caching data can be served for other consumers (efficient data dissemination) even when the original provider is not available due to a temporal network partition (resilient data dissemination).

A consumer can retrieve emergency data even in an intermittently connected or totally fragmented network during a disruption or disaster period, which shows the capability of DAN to cope with dynamic topology changes, e.g., caused by a reconstruction process by a network provider. DAN follows a communication model that is consumer or receiver driven, in which receivers can regulate if and when they wish to receive segments of data, so that continuous data retrieval from multiple DAN caching points is possible without setting up end-to-end sessions in the intermittently connected network. Also, due to the cache and forwarding function of DAN, a mobile DAN element can deliver emergency data among people in fragmented networks. At the same time, consumers are able to continue communication services, e.g., social networking services (SNSs), even after a disaster.

An operator can reduce the construction cost of a system that deals with disaster scenarios. Due to the name-based communication, there is no clear functional boundary between network elements and end devices in DAN. In this way, an operator can adaptively use available DAN elements as storage or caching servers during a disaster period, so that an operator can deal with a disaster scenario in an economical manner. Also, name-based communication enables the data object to be prioritized, so that appropriate action can be taken on individual data objects.

Moreover, DAN can regulate access to data objects, e.g., only to a specific user or a group of users, by securing the data object. This security mechanism facilitates trusted communications among end users in a fragmented network where public safety is disturbed and vandalism occurs frequently. These benefits have been shown in [b-Yo, 2013]; see also Appendix I.

7.6 Advanced metering infrastructure in a smart grid

The service scenario involves smart meters, communications networks and data management systems that provide two-way communications between utility companies and their customers. Customers are assisted by in-home displays, power management systems, etc. In communication networks, DAN elements can be installed in order to keep copies of data in the in-network caches so that the cached data can be reused in a format appropriate to the demands of customers and utility companies. Based on data that represent the pattern of use of a utility, customers can plan or limit the level of utility consumption and also utility companies can achieve load balancing in the network.

Figure 7-11 depicts a sample scenario for the AMI in a smart grid.

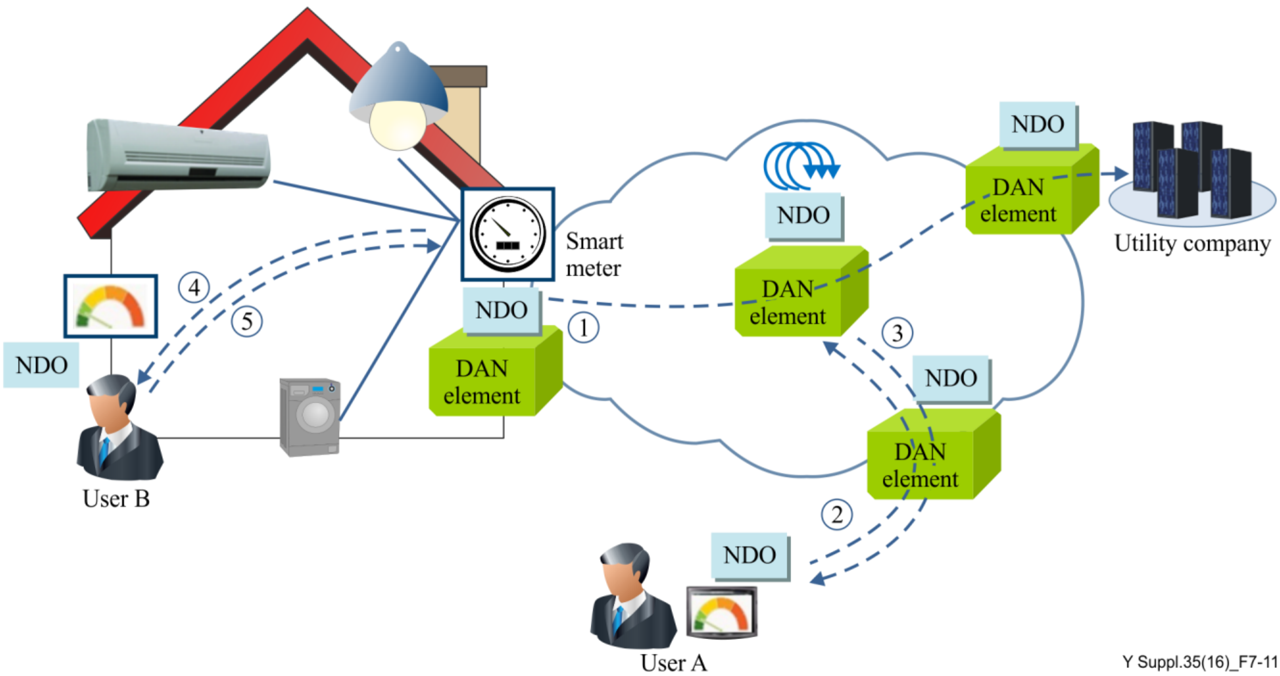

Figure 7-11 – Advanced metering infrastructure in a smart grid

The operational procedures of the scenario are as follows:

1) A smart meter records the energy consumption of home appliances in the storage of the DAN element, and regularly pushes the information, e.g., NDOs, to the utility company that provides electricity. While the NDOs are pushed to the utility company, they can be cached on selected DAN elements along the forwarding path, e.g., close to the end user.
2) User A, e.g., owner of a smart meter, requests information to check the states of appliances at home. At this time, the request hits the cached NDO on the DAN element.
3) The request is directly served from the DAN element, not from the smart meter. Moreover, the DAN element may process the NDO so that its format is suitable for the capability of user A's mobile device.
4) User B at home interrogates the smart meter regarding the energy consumption of home appliances.
5) The smart meter responds to the request.

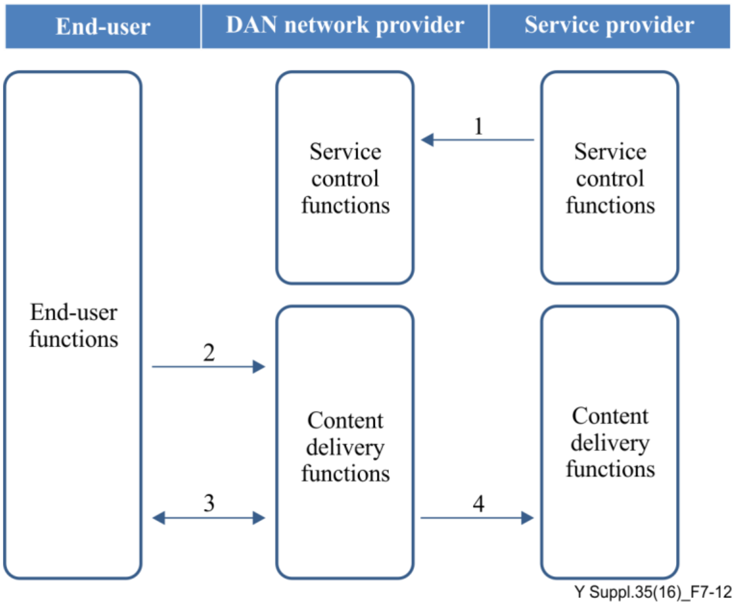

Figure 7-12 – Use case of advanced metering infrastructure in a smart grid with DAN

1) A service provider subscribes to NDOs. The service provider additionally specifies processing policy (e.g., aggregation and compression) that should be applied to the subscribed NDOs.
2) The end user publishes the NDOs.
3) The DAN network provider transfers the NDOs to end users on request.
4) The DAN network provider processes the NDOs based on the processing policy and forwards them to the service provider.

7.6.1 Benefits

Due to the in-network caching and processing functions of DAN elements, utility companies can use the network resource more efficiently in a way that data are distributed to the in-network caches where the data can be processed according to the demands of consumers and utility companies. In this way, load in the network can be balanced, which reduces the possibility of network congestion and the management cost of heavily loaded network entities in a scalable manner. These benefits have been shown in [b-Yu, 2014]; see also Appendix II.

Moreover, current implementations of AMI use either dedicated networks or the Internet via home routers. The former can support reliable communication only for involved network operators, while requiring large investment to build the network infrastructure. Although the latter is appreciated due to its economical perspective, it requires customers to set up virtual private network (VPN) connections for reliable and secure communications, which is troublesome. DAN secures data itself rather than a connection between two communication entities, and the configurations of DAN home routers are universal or not site-dependent. Thus, DAN discards the requirement of site-dependent VPN setup, and then enables a service provider to deploy the AMI system over public networks like the Internet in a fast and economical manner without concerns about securing the connections.

7.7 Proactive video caching

This service scenario involves passengers on moving vehicles (train, car, bus, etc.) who watch video content over the Internet with their portable devices (smartphone, laptop, etc.). In the case of a moving train, the video content being watched is proactively cached at every DAN element in each station according to the scheduler that decides how much video content should be proactively cached based on video and transportation information. In the case of other means of transport whose moving direction is not predetermined, location information from the navigation system can be used to choose the DAN element where the video content is cached proactively.

Figure 7-13 depicts a sample scenario for proactive video caching.

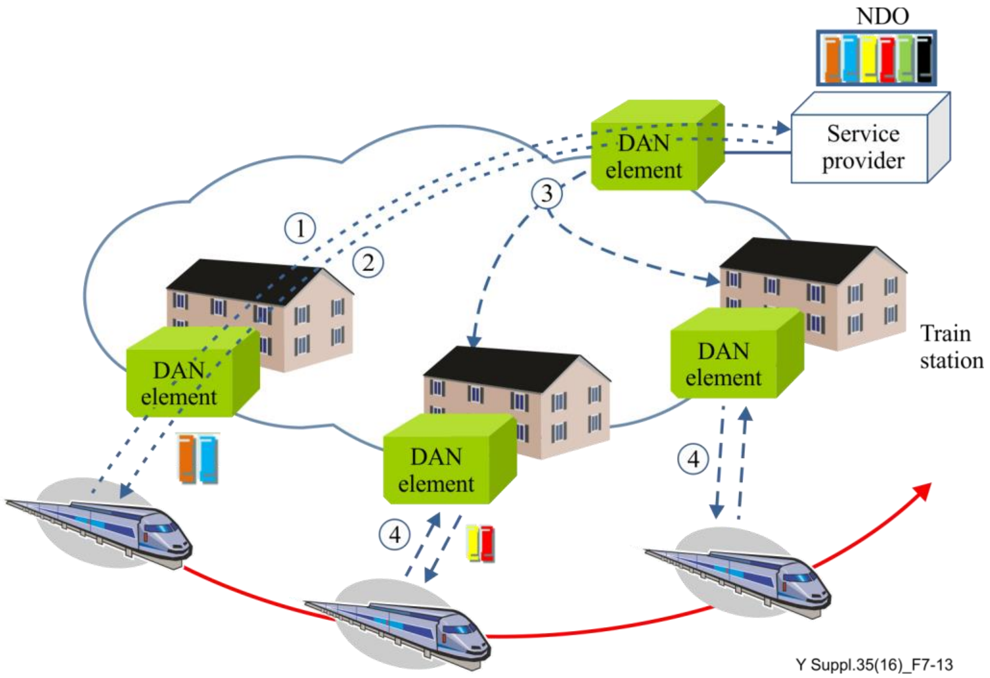

Figure 7-13 – Proactive video caching

The operational procedures of the scenario are as follows:

1) An end user in a train requests a cinema film, i.e., an NDO, from its service provider.

2) The end user begins watching the film.

3) The service provider pushes the segments of the film file to the DAN nodes in the stations that the train will pass through.

4) As the train passes through stations, the end user is able to access and retrieve the segments that will be watched next.

Figure 7-14 is a procedural diagram of DAN functions for this scenario.

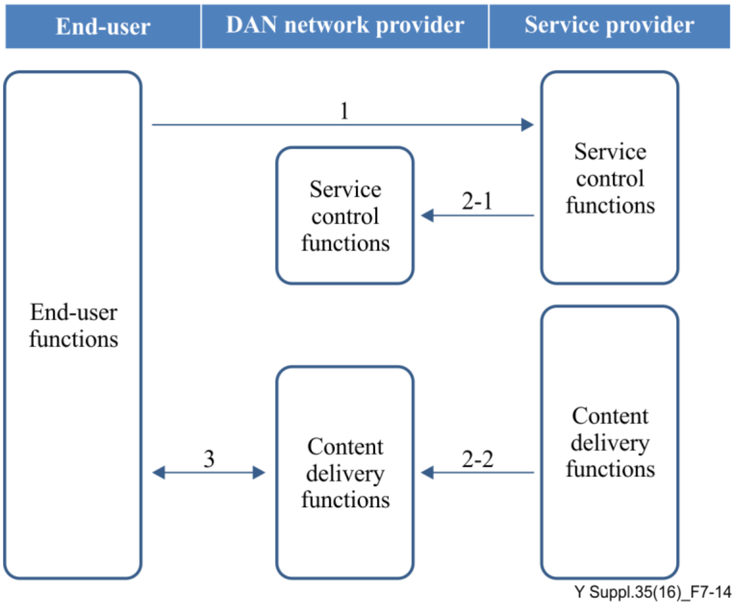

Figure 7-14 – Use case of proactive video caching with DAN

1) The end user sends a request to subscribe to a film to the service provider.

2) The service provider calculates the future locations of the end user, e.g., based on the train timetable, and the network bandwidth at the locations (labelled 2-1 in Figure 7-14). Then, the service provider pushes the segments of the film file to the relevant DAN nodes (2-2). Moreover, the service provider provides the DAN elements with its public key that authorizes the DAN elements to serve the corresponding segments of the film.

3) The end user accesses the DAN node and retrieves the segments of the film.

7.7.1 Benefits

The quality of video delivery to mobile users can be significantly improved by using the proactive video caching mechanism supported by DAN. Since the video content being watched is pushed to the relevant DAN elements in advance, it can be served immediately as soon as the mobile user changes the DAN element to which it is attached. Thus, delay is minimized due to the reduction of the number of hops through which the video content travels. Moreover, the cached video contents in the DAN elements can be accessed by all subsequent mobile users.

Network operators can also benefit from this service scenario. First, the network bandwidth consumption decreases due to the reuse of video contents in caches. Second, it is possible to reduce the level of energy consumption of the network by accessing video contents through WLAN, which in general requires less energy for transmitting data than cellular networks.

The benefits of proactive video caching have been shown in [b-Kanai, 2014]; see also Appendix III.

7.8 In-network data processing

This service scenario describes DAN as an in-network data-processing platform for an efficient IT system. This service enables users to process data in a fast and flexible manner by distributing data-processing functions and adaptively moving them over ubiquitous DAN elements, such as those on the edge of the network and at concentrated points of data-processing requests. A similar concept that focuses on mobile edge deployment has been proposed in [b-MEC, 2014]. On the other hand, this service scenario supported by DAN can provide more flexible features, such as mobility, network-wide deployment and caching of data-processing functions.

NDOs in DAN are typically conventional data, such as videos, text files and measurement data. At the same time, an NDO can also represent a data-processing function. When a need arises to clarify whether an NDO represents conventional data or a data-processing function, it is specified as NDO-data or NDO-func, respectively. An end user can request a data-processing function by its name without knowing its location [b-Tschudin, 2014].

This service scenario takes into account that DAN elements can: 1) execute data-processing functions; 2) move data-processing functions autonomously or manually; and 3) cache not only data, but also data-processing functions. Thus, DAN elements close to an end user can cache data and data-processing functions, as well as directly responding to various user requests. In this manner, traffic load in the core network and the response time for user requests can be reduced. Nevertheless, the deployment of the data-processing function should be decided carefully considering various functional allocations to optimize the system [b-Katoh, 2015].

Typical implementations of this service scenario include video analysis and the Internet of things (IoT). For instance, when a large quantity of video data from a camera is requested for analysis, e.g., to detect lost children or to monitor unattended properties, the analysis request may be carried out in the DAN element close to the video data source rather than being forwarded to a remote server. This strategy is adopted because the transmission time for a large video file to a remote server through a WAN would be the dominant element in total delay, although data-processing time is also usually relatively large. In addition, if the remote server is congested with many other tasks, the analysis request may be carried out in the DAN element close to the requester rather than on the remote server, because the load on the DAN element might be comparatively low. In these cases, the transmission times of request and response messages can be reduced effectively within the total delay or data-processing resources can be used more efficiently due to distributed processing over ubiquitous DAN elements.

Regarding NDOs in DAN caches, there are two cases. The first is when the DAN element has the result of a data-processing function for an analysis in its cache, which directly returns the data to the requester. The second is when the DAN element has a function in its cache that processes input data with the function and returns the result to the requester. Otherwise, the analysis request is forwarded to another nearby DAN element that holds the function.

Figure 7-15 describes a sample scenario for in-network data-processing service with DAN.

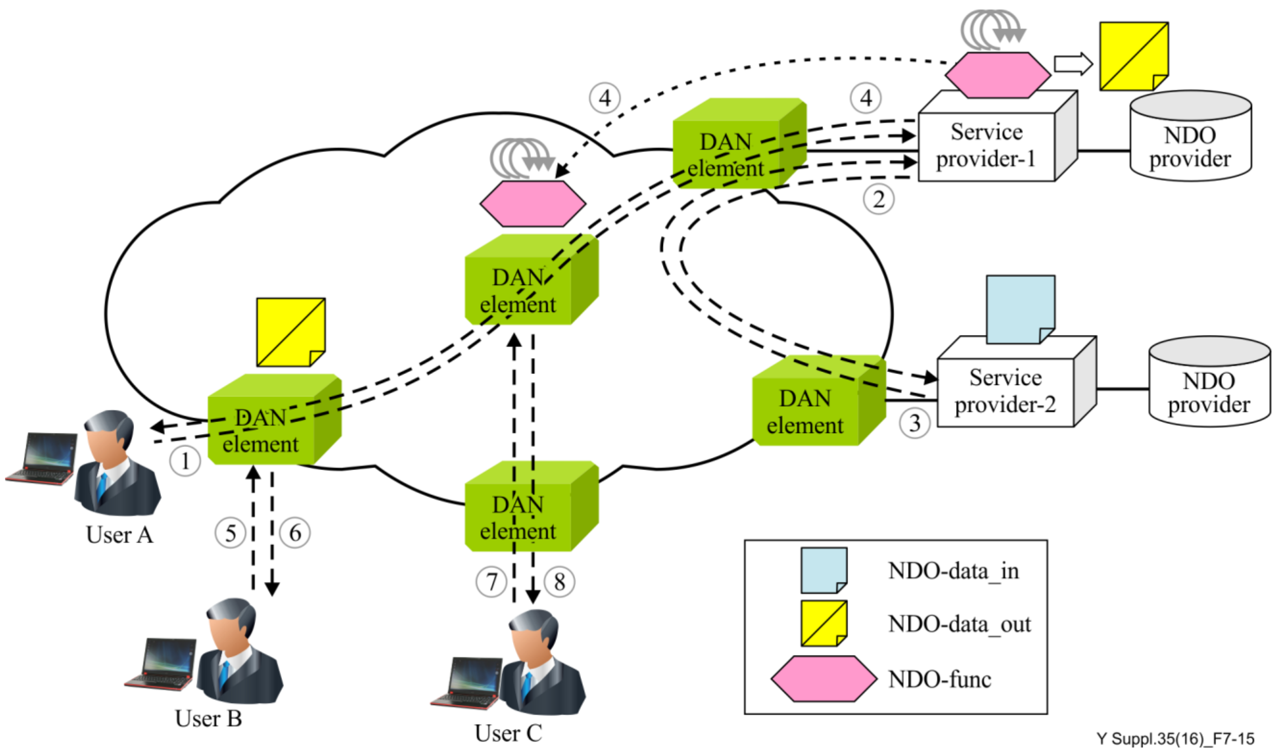

Figure 7-15 – In-network data processing with DAN

The operational procedures of the scenario are as follows:

1) User A requests an execution of NDO-func (data-processing function) from its service provider (labelled Service provider-1 in Figure 7-15). The name of NDO-func is accompanied by that of NDO-data_in.

2) To execute NDO-func, Service provider-1 requests NDO-data_in from its service provider (Service provider-2).

3) Service provider-1 receives NDO-data_in from Service provider-2. Then, it executes NDO-func with NDO-data_in, and produces NDO-data_out (output data: result of the execution).

4) While NDO-data_out is downloaded from service provider-1 to User A, it can be stored on selected DAN elements along the downloading path. In addition, NDO-func can be pushed to selected DAN elements or pulled by other DAN elements when it is necessary.

5) User B requests an execution of NDO-func which specifies NDO-data_in as an input to the service provider. At this time, the request hits the cached NDO-data_out on the DAN element.

6) Since NDO-data_out is the result of the processing function NDO-func acting on NDO-data_in, it is directly served from the DAN element, not from the service provider.

7) User C requests an execution of NDO-func that specifies NDO-data_in as an input to the service provider. At this time, the request hits the cached NDO-func on the DAN element.

8) Thus, the DAN element only requests NDO-data_in (omitted in Figure 7-15) to Service provider-2. Then, it executes NDO-func as an input NDO-data_in, produces NDO-data_out, and finally delivers it to User C.

Figure 7-16 is a procedural diagram of DAN functions for a DAN in-network data-processing service.

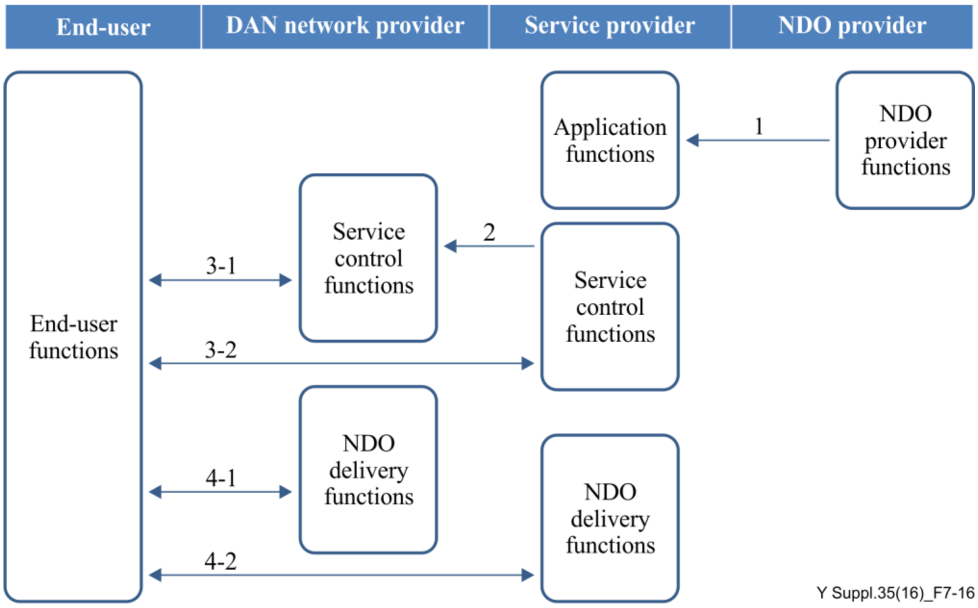

Figure 7-16 – Use case of in-network data processing with DAN

1) An NDO provider provides the data-processing function (NDO-func) and data (NDO-data, typically input data to the function) for the service provider.

2) The service provider publishes the NDOs (NDO-func and NDO-data), which distributes routing information that leads toward the NDOs.

3) When an end user wants to execute an NDO-func, the request is sent to the DAN element close to the end user that holds the NDO-func or NDO-data as a result of the execution in its

cache or storage (labelled 3-1 in Figure 7-16). Otherwise, the request is directly delivered to the service provider (3-2).

4) Either the DAN element (4-1) or the service provider (4-2) supplies the NDO-data as a result of the execution to the end user. If NDO-func is a DAN element, the DAN element executes the NDO-func, produces NDO-data as a result of execution and supplies it.

7.8.1 Benefits

A network operator can benefit from this DAN service scenario because of the reduction of traffic load in the core network and CPU load in the computing servers, thanks to the ubiquitous caching capability of DAN, which also enables load balance in a native manner.

An end user can benefit from DAN because of the shortening of the response time due to the fact that data as well as data-processing functions can be cached close to the end user and directly serve user requests from the caching points. In addition, since the whole data-processing operation can be carried out between the end user node and nearby caching nodes, the risk that user information gets intercepted is relatively low, which protects user privacy in an appropriate manner.

An application developer can benefit from DAN in regards to easy programming of network applications, e.g., easy specification of interfaces for calling other applications by name.

7.9 Multihoming with DAN

Nowadays mobile devices are equipped with multiple wireless interfaces such as bluetooth, WLAN and long-term evolution (LTE). Each of them has unique advantages in terms of bandwidth, network access costs, coverage, etc. However, current IP networks cannot fully utilize the benefits because they basically cannot forward selected data flows to a specified network interface.

DAN is based on the operation of name-based routing where each data flow is identified and forwarded to selected network interfaces. For this reason, DAN is able inherently to support this service scenario.

Figure 7-17 depicts a sample scenario to support a multihomed mobile device using DAN. Suppose three end users, S1, S2 and S3, in a train want to watch a TV programme with their smartphones, which have different types of wireless interfaces, e.g., bluetooth, WLAN and LTE.

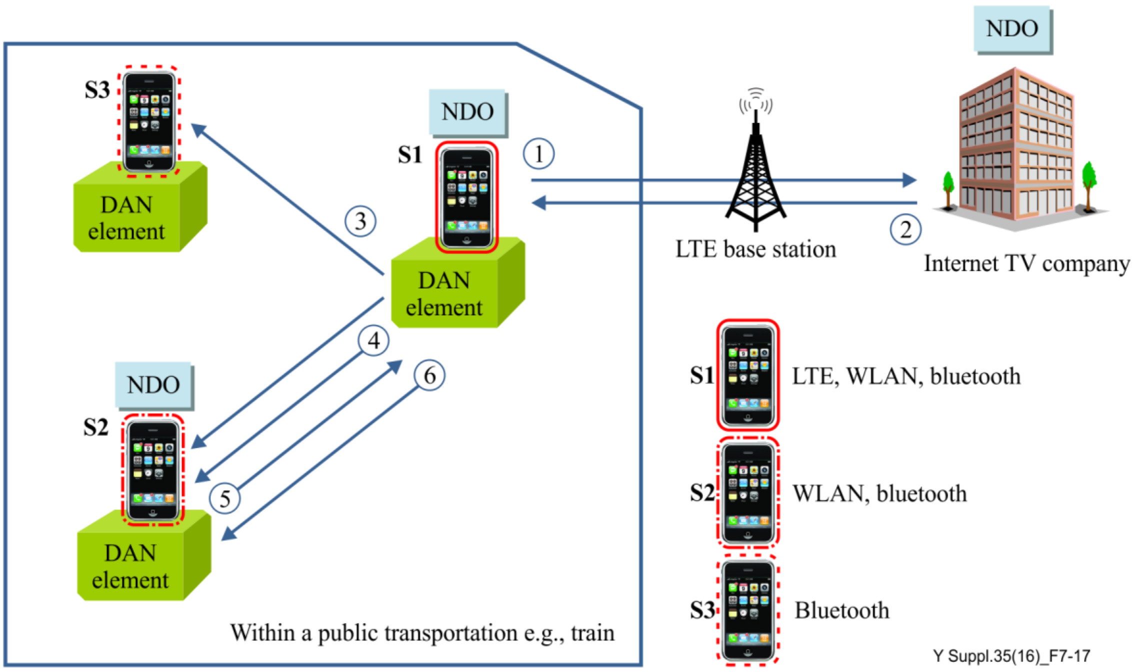

Figure 7-17 – Multihoming with DAN

1) End user S1 in the train requests a TV programme, i.e., an NDO from its TV service provider through its LTE interface.

2) The service provider transfers the NDO to the requester. The device of S1 caches it.

3) The device of S1 announces to its neighbours the existence of the NDO through the broadcast functions of bluetooth. The announcement is delivered to both S2 and S3.

4) The device of S1 announces to its neighbours the existence of the NDO through the broadcast function of WLAN. The announcement is only delivered to S2, which receives two announcements from S1 through its bluetooth and WLAN interface, respectively.

5) S2 requests the NDO from S1 via WLAN since WLAN is faster than bluetooth.

6) S1 transfers the NDO to S2. The device of S2 caches it to serve other neighbours on demand.

Figure 7-18 is a procedural diagram of DAN functions for this scenario.

1) The service provider publishes NDOs, which distributes routing information that leads toward the NDOs.

2) The DAN network provider forwards the routing information to the end user.

3) The end user requests the NDO through an appropriate interface, which is determined based on the routing information.

4) The DAN network provider transfers the NDO to the end user.

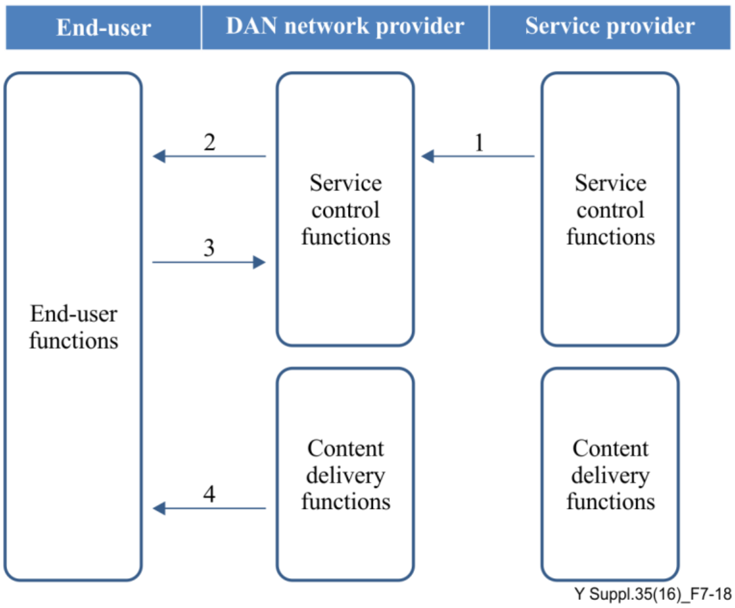

Figure 7-18 – Use case of multihoming with DAN

7.9.1 Benefits

DAN provides us with the capability to obtain any data in heterogeneous networks using the same ID of the corresponding NDO. Users do not care about which media interface is active to access their favourite data in the possible networks surrounding them, such as a bluetooth network, Infrared Data Association (IrDA) network, WLAN or the Internet via LTE. Thus the user interface is dramatically improved. Furthermore, an application developer can also benefit from DAN because of easy programming for network application, e.g., ease of access any data by its unique name.

Network operators can improve network bandwidth consumption from this service scenario, since DAN is able to retrieve NDOs through multiple network interfaces simultaneously. Network interfaces can be also adaptively used based on an environmental change, so that a user does not need to care about how much of each network is currently used. Fault tolerance of communication between two DAN nodes can be achieved if the nodes have several network interfaces between them. Since different types of access networks have different scopes in terms of coverage, one link failure due to movement outside the link coverage can be compensated for by another link that is still connected to the other network.

Furthermore, application developers can benefit from DAN because of easy programming for network application because they are not required to worry about the specification of network interfaces.

7.10 Traffic engineering of DAN

This service scenario takes advantage of the awareness feature of DAN, which inherently enables DAN elements to identify not only individual flows of data objects on the network level, but also their features such as the size or the service requirements of data objects. Thus, flows of data objects can be treated differently by forwarding them through different paths depending on their service requirements. In IP networks, an additional system component, e.g., deep packet inspection, is required to support such a function. For instance, the problem of mice and elephant flows is well known: mice flows are short-lived data flows such as emails, web pages, and data requests; on the other hand, elephant flows are long lived, such as video streaming and data migrations, which significantly impact on network bandwidth and performance.

For dynamic operation of the service scenario when confronted with substantial data flow, DAN can be managed in a centralized manner. A central management unit of DAN recognizes substantial data flow coming into the network and dynamically sets up routes for the flow. For this reason, DAN elements are deployed by operators for efficient use of network resources and fine control over user traffic.

Figure 7-19 depicts a sample scenario for DAN traffic engineering. This scenario assumes two types of application: making phone calls; and downloading files. From the quality of service point of view, a phone call service has higher priority than a file download service, since the phone call service requires minimum packet loss and latency. To optimize data flows in this scenario, the two data flows are identified with their names including labels specifying their service requirements: "Phone" for phone calling; and "FDS" for file downloading.

1) User A requests User B for a telephone call. By the label "Phone" in the request message, e.g., "/Phone/UserA" and "/Phone/UserB", DAN elements are aware that the traffic is delay sensitive and so forward the request message following the shortest path.
2) User B responds to the request and forwards the voice data objects to the DAN network. The voice data objects are routed through the path that minimizes the delay. The caching function of DAN elements on the path is disabled since it is a phone service.
3) During the phone conversation, User A requests an NDO from its file downloading service provider with its name "/FDS/NDO", which represents delay insensitive traffic.
4) The service provider responds to the request and forwards the NDO to the DAN element. By the name of "/FDS/NDO", the DAN element identifies that this is delay insensitive traffic flow and routes it to the path that is not overlapped with the path taken by the voice data traffic flow, and that is possibly having wider broadband. The cache function of the DAN elements on the path is enabled to cache the NDO.

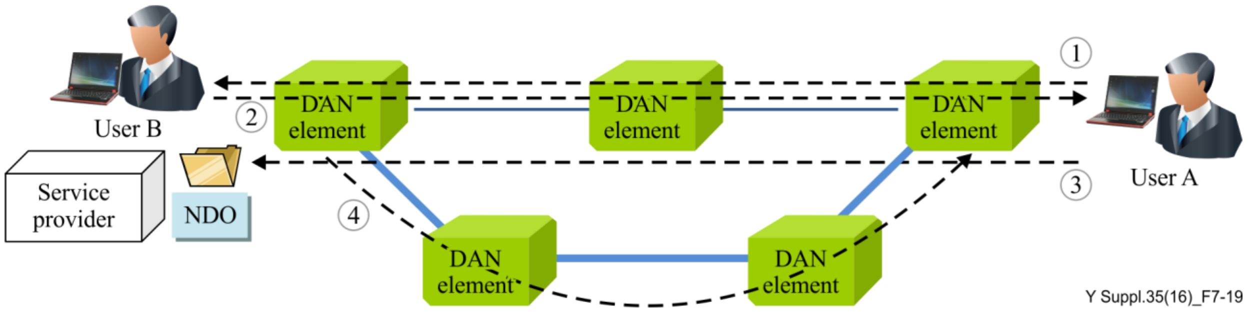

Figure 7-19 – Traffic engineering of DAN data flows

Figure 7-20 is a procedural diagram of DAN functions for this scenario.

1) The service provider transmits the QoS requirements of the NDOs to the DAN network with labels in the names of the NDOs, e.g., "/Phone/" or "/FDS/".

2) The end user requests an NDO from its service provider with the names, e.g., "/Phone/NDO" or "/FDS/NDO".

3) The traffic control functions of the intermediate DAN elements identify the required QoS of the request by the name and inform its content delivery function how to forward the requested NDO to the end user.

4) The service provider forwards the requested NDO to the DAN network.

5) The DAN network determines a route based on the QoS requirement of the requested NDO and the information of DAN networks, e.g., traffic and topology. The NDO is forwarded to the end user following the determined route.

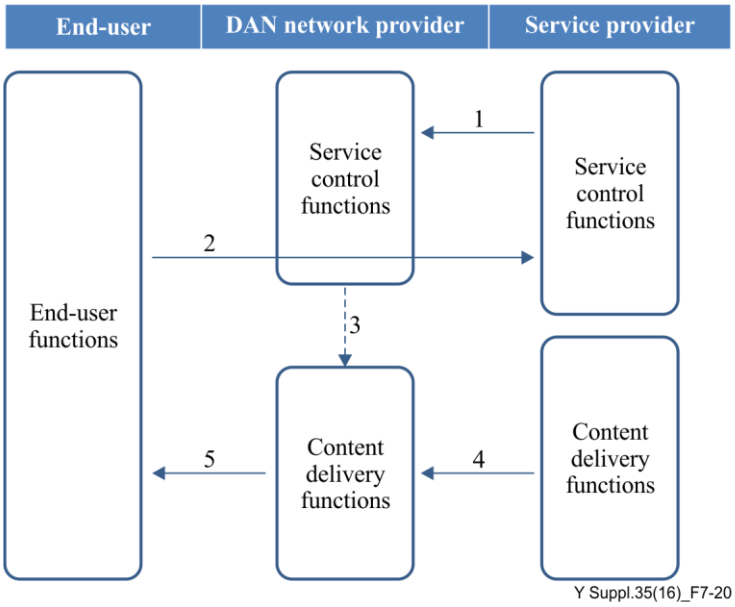

Figure 7-20 – Use case of traffic engineering DAN

7.10.1 Benefits

The properties of data objects are exposed to DAN elements in the form of the names or the attributes of the data objects, which is known as the data awareness of DAN. The properties enable DAN elements to treat individual data flows differently according to their requirements, e.g., delay sensitive or network conditions. While such an awareness feature in DAN is supported in a native manner by the architecture, conventional networks need a technology, e.g., deep packet inspection (DPI), to be aware of data flows.

Moreover, conventional networks secure connection, not the data object individually. For instance, the hypertext transfer protocol – secure (HTTPS) widely adopted in recent years disables the awareness by encrypting data flows from one end to the other. Thus, even though different types of data objects, e.g., cacheable or non-cacheable, are transferred through the secure connection, it is not possible to differentiate the data objects and cache them selectively. On the other hand, DAN deals with individual data objects selectively for caching or processing because its security mechanism is applied for each data object rather than the connection.

With this service scenario, network operators can use the network resource more efficiently by enforcing data flows to follow less utilized paths in the network. At the same time, network operators can also provide more elaborated service for end users since they can identify data flows and treat them differently based on the requirements. This service scenario shows a potential possibility of how DAN can be operated within the framework of software-defined networking (SDN), which is characterized by a well-defined separation between user and control planes.

8 Migration

Implementation of each service scenario is subject to the migration from current networking to DAN. Nevertheless, the migration can be gradual. There are two deployment options.

One deployment option is based on network virtualization technology, which includes an overlay model and slice model. In the overlay model, DAN elements are selectively placed inside the current network. This model is cost-effective due to the use of IP networks for networking remote DAN elements. As the number of DAN elements increases, DAN can provide more efficiency and scalability. DAN elements can be used as gateway nodes next to the conventional network elements and serve the desired functions for each service scenario like caching, aggregation and protocol translation between DAN and the existing network, etc. In the slice model, a network slice is created on the current network and DAN is deployed on the slice. This model has the merit of easy extension by horizontal or vertical cooperation with other slices.

The other option is based on a clean-slate mechanism, where the IP layer of the current network is totally replaced by the name or ID layer of DAN for name-based routing. This option can utilize DAN capabilities most effectively. However, it is realistic to use network technology properly according to network usage and service requirements, rather than replacing hastily all networks by DAN. Actually, this replacement could be done gradually on the basis of management domain. For example, a newly introduced network may be constructed on pure DAN technology. DAN elements on the edge should provide gateway functions as well, so that DAN and existing networks can communicate with each other.

9 Environmental considerations

Environmental considerations in this Supplement are mainly subject to those provided by DAN: its extra energy consumption due to the requirement for additional resources (e.g., cache or storage) for its operation. Thus, the environment considerations specified in [ITU-T Y.3033] would be sufficient for this Supplement.

10 Security considerations

The security consideration in this Supplement are mainly subject to the security mechanism provided by DAN, which secures each data object based on the signature of its publisher rather than securing the connection between two end points. This security mechanism assumes that users can access the public key infrastructure. However, this assumption may not be valid in some DAN service scenarios, such as networking in a disaster area where users are isolated from the public key infrastructure. Therefore, an additional security mechanism may be required for a particular DAN service scenario.

Appendix I

Efficient and resilient data dissemination in a disaster area

Figure I.1 shows the packet loss as a function of the number of connections that simultaneously connect to an original content holder located at the top of a tree topology. Due to the in-network caching function of DAN, contents originally located at the top of a tree topology are gradually distributed to the in-network caches in the network, which enables DAN to provide an efficient as well as resilient data dissemination scheme for any disaster scenario. The simulation was carried out based on named data networking (NDN) [b-Jacobson, 2009], which is an example of an implementation of DAN.

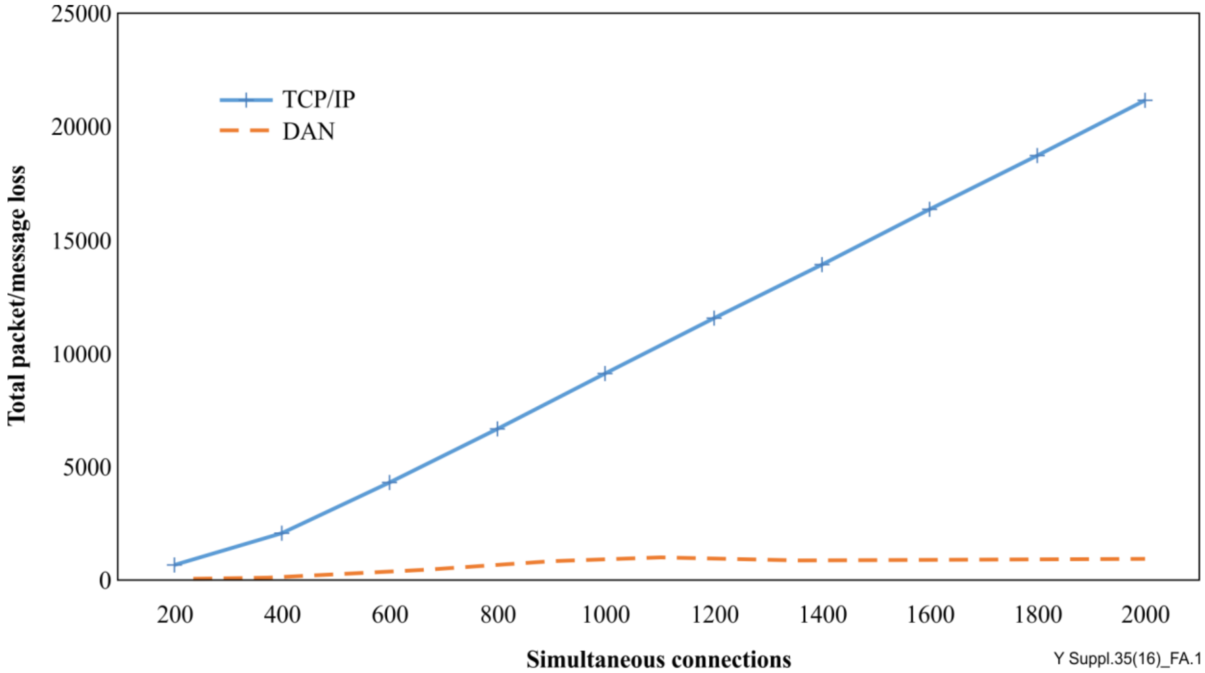

Figure I.1 – Packet loss versus number of connections that simultaneously connect to an original content holder

Appendix II

Design of advanced metering infrastructure in smart grid with DAN

Figure II.1 shows the design of AMI with DAN. The architectural components of DAN, such as naming, routing, caching and forwarding (right-hand side), can correspond with the transport and network layer protocols [e.g., transmission control protocol/transport layer security (TCP/TLS) and IPv6] in the current protocol stack of AMI (left-hand side).

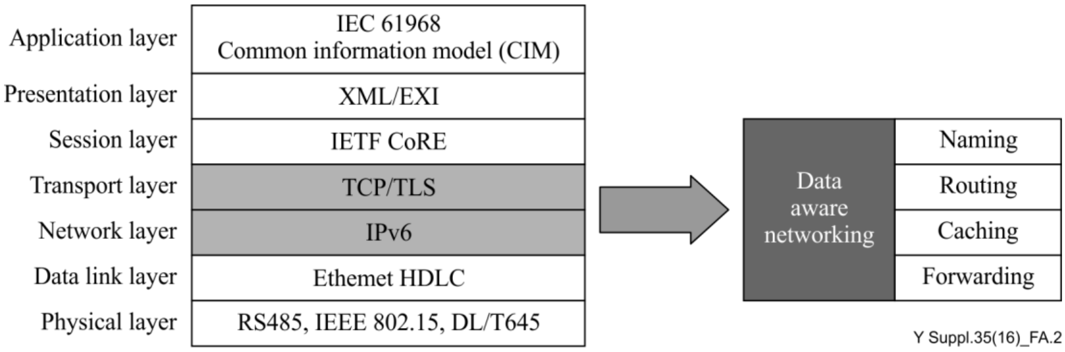

Figure II.1 – Protocol stack of advanced metering infrastructure with DAN in [b-Yu, 2014]

Figure II.2 shows how much bandwidth is consumed when the same size content is transferred in AMI based on DAN (DAN-AMI) and IP (IP-AMI) networks, respectively. In the simulation, 240 smart metres were pushing data objects to DAN-AMI as well as IP-AMI, and subscribers retrieved the data objects from the network. Due to the in-network cache and processing functions of DAN elements, requests from subscribers were directly served by the individual DAN elements holding the data objects and so the network bandwidth consumption in DAN was significantly reduced compared to IP. The simulation was carried out by using the NDN simulator [b-ndnSIM].

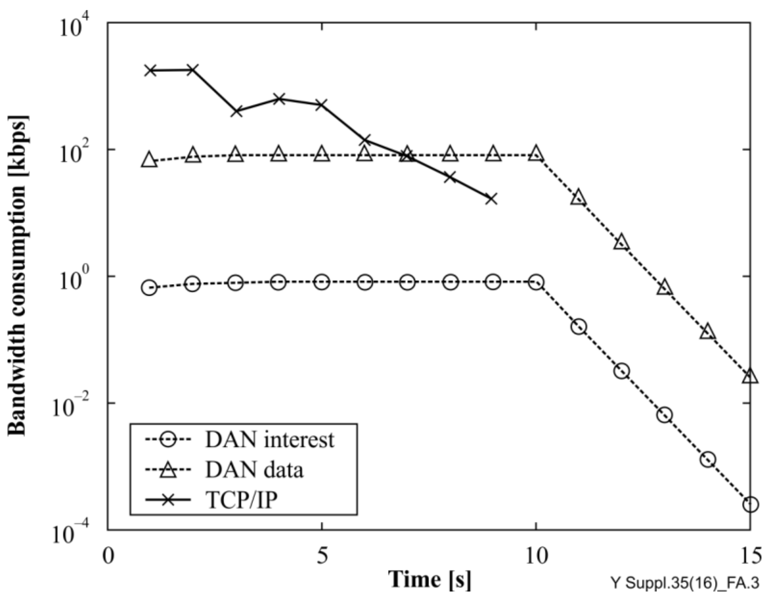

Figure II.2 – Bandwidth consumptions in DAN-AMI and IP-AMI (see [b-Yu, 2014] for details)

Appendix III

Proactive video caching with DAN

Figure III.1 shows the experimental configuration of the proactive video caching mechanism with DAN. There are three stations equipped with DAN elements and the content source provides video. Video contents are proactively cached in the DAN element in every station using the scheduler, which decides how many video contents should be proactively cached based on the train schedule. The experiment was carried out based on NDN implementation.

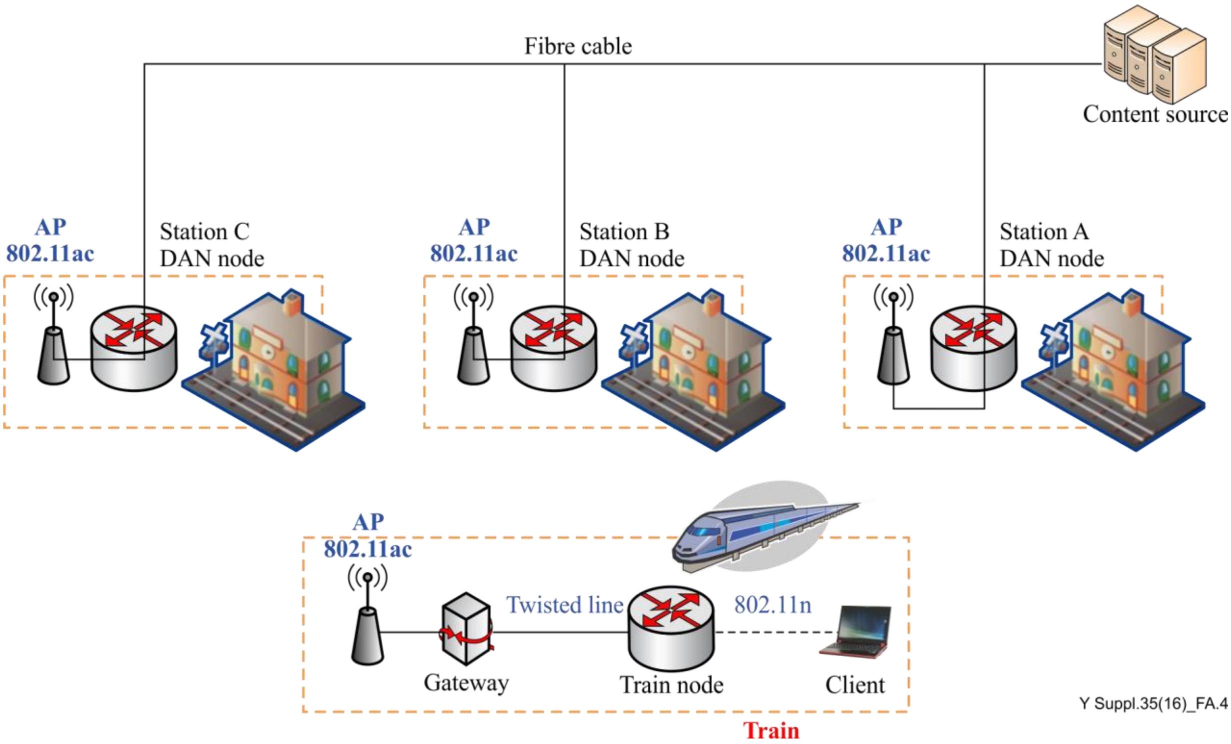

Figure III.1 – Experimental setup for proactive caching mechanism with DAN

Figure III.2 shows the throughput changes as the mobile user on the train moves from station A to station C. The red, green and blue lines show the throughput at each DAN element when the train stops at each corresponding station, respectively. The pink line shows the throughput observed at the user device. The black line shows the total of all throughputs, which are defined previously. The scheduler makes sure that the video content being watched is proactively cached in every station before the train arrives there.

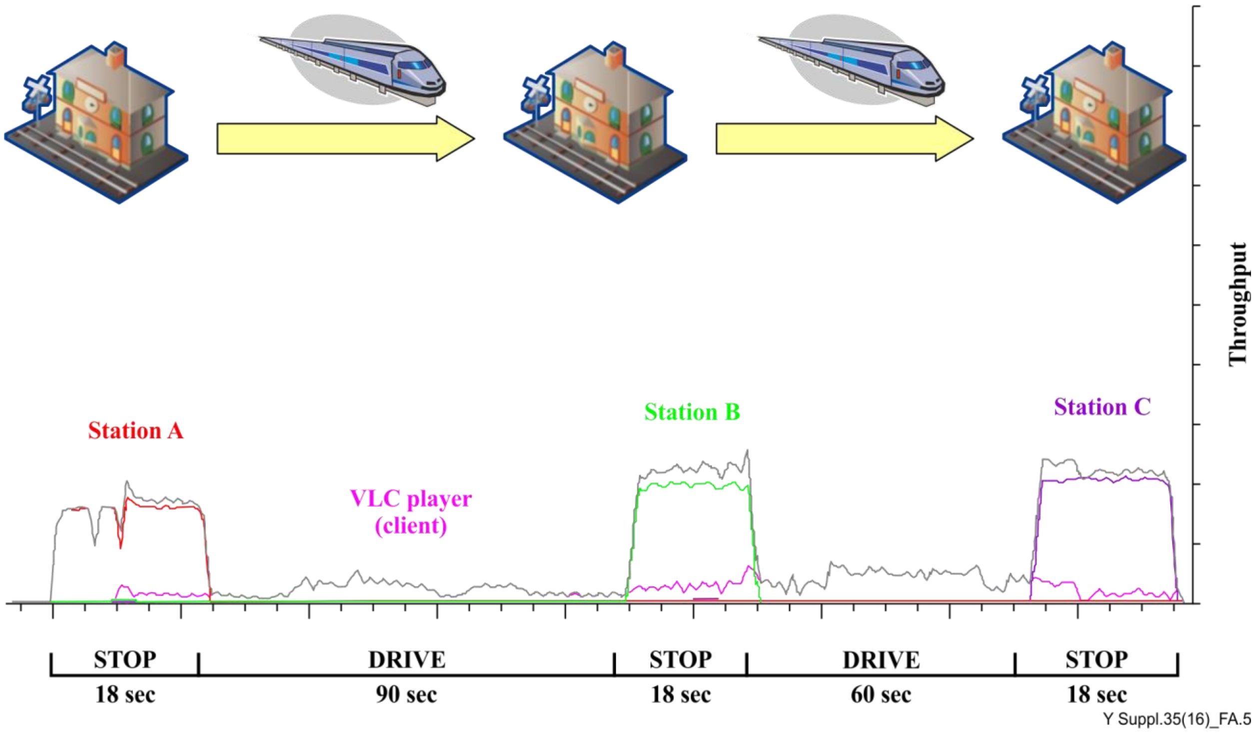

Figure III.2 – Variations of throughputs as a mobile user on a train moves from station A to C

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