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Digital Audio Broadcasting (DAB)-based demand response for buildings, electric vehicles and prosumers (DAB-DSM)

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Abstract

The main objective of this paper is to present a new and cost-effective Information and Communication Technology (ICT) tool that can lead to efficient energy management in buildings and optimal operation of electricity networks with increased share of Renewable Energy Sources (RES) and Electric Vehicles (EVs). The new ICT infrastructure is based on the Digital Audio Broadcasting (DAB) standard and its interoperability with smart metering technology, Intelligent Transportation Systems (ITS) and Building Automation Systems (BAS). The main idea involves the attachment of a DAB receiver to electric devices (from small household appliances up to EVs and solar systems and other RES). In this paper, the DAB protocol is described, enabling high cyber-physical security. Moreover, the results of addressing a thermostatically-controlled load using DAB-signaling in Switzerland are also presented. The next steps envisioned are i) the validation of the final protocol version and of the DAB receivers for various electric appliances and DR schemes and, ii) demonstration of the new technology in real-life cases through the National DAB broadcaster in Greece.

Keywords: Demand side management;Microgrids;DAB standard;Virtual power plants; Secure building automation systems (BAS); Intelligent Transportation Systems (ITS);E-Vehicle to Infrastructure (V2I)

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1. Introduction

Nomenclature

BAS	Building Automation System
DAB	Digital Audio Broadcasting
DG	Distributed Generation
DR	Demand Response
DSM	Demand Side Management
DSO	Distribution System Operator
EV	Electric Vehicle
G2V	Grid To Vehicle
ICT	Information and Communication Technology
ITS	Intelligent Transportation System
Prosumer	The electric energy consumer who becomes also a producer of electricity
PV	Photovoltaic
RES	Renewable Energy Sources
V2I	Vehicle To Infrastructure
VPP	Virtual Power Plant

The trends of increasing urbanization, thus increasing number of electric appliances, as well as the expected penetration of heat pumps and EVs, lead to the conclusion that the electricity demand in urban areas in Europe will rise in the near future. On the other hand, all European Union (EU) countries have the commitment to increase the share or Renewable Energy Sources (RES), which however are variable and nearly non-controllable, having a high uncertainty degree. Therefore, in many EU countries, the current regulation foresees premium access to the grid for RES. Consequently, weather-dependent RES, such as PV-plants and wind-farms, operate at their maximum possible outputs whenever technically possible and, therefore, do not follow the variation of energy consumption. In high RES penetration cases, and especially whenever local grids (e.g. microgrids) or isolated energy networks (e.g. islands) are considered, the above operational principles and trends include the risk of reduced reliability of power supply to the consumers [1-9]. Hence, a holistic approach is required that will enable increased RES participation into the energy mix, while ensuring grid stability and consumers' satisfaction by using replicable, cost-effective and advanced communication tools, especially for the demand side and for the efficient implementation of DR schemes.

DAB is a unidirectional signaling process, which means that it acts complementarily to other communication technologies that are envisaged to be used in smart grids applications. Thus, advanced cloud services, GSM, WLAN home routers, data collectors, etc., will be utilized only for the data transmission and feedback by the applied DR-schemes. Therefore, the DAB signaling does not add any complexity to the Smart Grid Architecture Model [10]. On the contrary, (a) it simplifies things, since it removes the one-way communication burden from the rest communication networks in a cost-effective way, (b) there is no need to install interfaces-gateways with IP addresses in each electric appliance, (c) cyber-security and data protection issues are intrinsically solved with DAB service, (d) the DAB technology complements the functionality of many smart meters: While most smart meters are used for automated reading of the meter data, DAB can be used to send price signals directly to loads. This does not increase the overall complexity of the system, rather simplifies it. DAB transmits data directly to the loads while the smart meters provide information about the reaction of the loads to this data. DAB energy data receivers can also be appended to the smart meters, enabling automated electricity cost calculation for consumers.

The main idea involves the attachment of a DAB receiver to electric devices (from small household appliances up to EVs and PV units) in order to enable DAB-based switching of electric loads and Distributed Generators (DGs). As a second step, the aim is to have the manufacturers of the devices integrate a receiver already from the factory. This integration can involve also several DAB services, from which the user can pick one using displays and controls on the devices. The functional architecture for the application of the DAB concept is shown in the following figure:

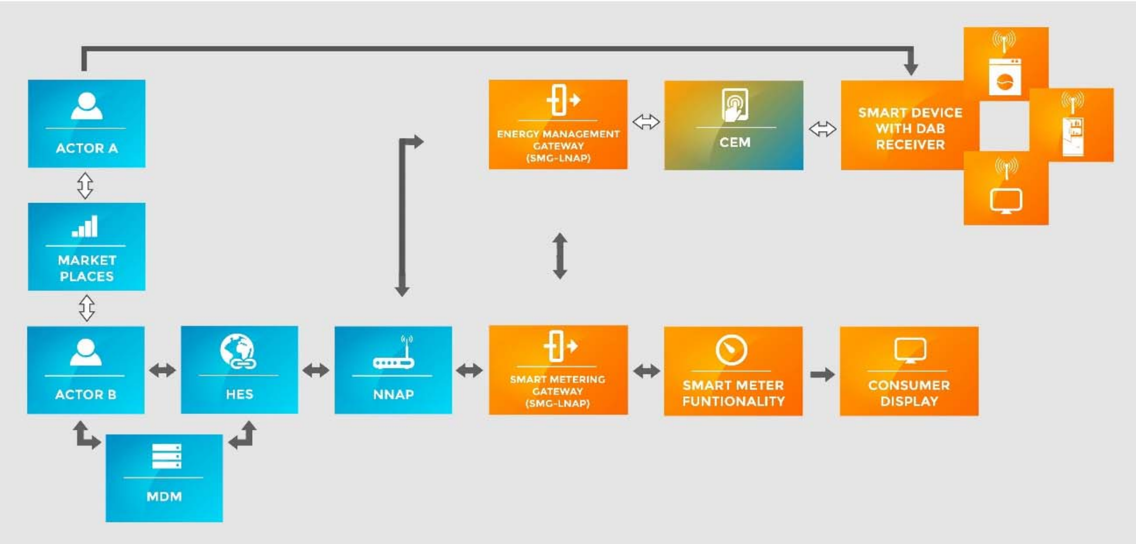

Fig. 1. Proposed functional architecture for the DAB concept applied to DSM [10].

2. Concept analysis

The overall concept is best illustrated in Fig. 2. It shows the flow of information, highlighting the most relevant actors. Energy Providers or Energy Market actors (or, as example, a balance group) have the need to alter the demand side, either due to financial/price conditions or due to network stability. They will send control signals to a large pool of electric loads. This data is broadcasted, using DAB, to the loads. The loads will react as a pool to this signal; single loads that may not receive the signal will not pose a problem, as a large pool of loads will be addressed and only their collective reaction to the signal matters. To inform about the pool reaction, smart meters and other measurement equipment, which is already installed in the network, is used as a backchannel. This data is made available to the energy provider which has initiated the action for evaluation, thus closing a circle of information flow.

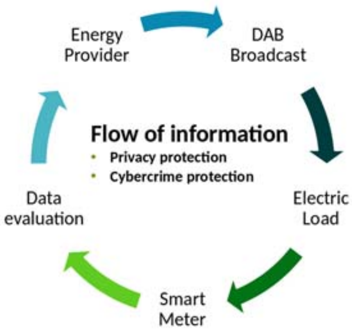

Fig. 2. Flow of information and the relevant actors.

The advantages of using unidirectional DAB signaling are the following:

- DAB is one of the cheapest technologies as it exploits synergies with radio programs, has very cheap and established infrastructure costs as well as inexpensive receiver technology, and this maximizes the total load which can be exploited for demand response. A large city can be connected with a single antenna; for example, compare GSM with 1000 antennas for Berlin vs. 1 antenna for DAB vs. 1 million routers/home WLAN installations for WLAN connectivity.

- It is the most promising technology for applying emergency grid stability actions, since it reaches simultaneously to a great number of appliances with minimum time delays.
- It has very good reliability; it has emergency battery supply in the case of a blackout which is much more robust than other technologies.
- It can be easily integrated into existing devices/appliances. Therefore, a much larger market can be addressed.
- It is future proof (compared to FM radio, even though both systems may exist in parallel for some time).
- It can be combined with local voltage/frequency measurements to obtain a technology with very high protection with respect to cyber-security issues.
- There are no privacy/data protection issues.
- There is reception in buildings and outside.
- It is one of the few demand response technologies that can be easily attached to special loads, like pumps used in agriculture, etc.
- In a final solution, the DAB receivers are integrated into the appliances by the manufacturer already, bearing also a "DR-enabling label" in analogy to the "EU energy label" for devices which support this feature.

A secondary concern is the extension of DAB protocol communication to EV charging. A strong advantage of the DAB standard is that vehicles in general and of course EVs are going to have DAB integrated anyway. These new features of EVs will enable smart charging for efficient allocation of EV demand through the day and, moreover, will improve the distribution system reliability by G2V operation of EV parking lots and domestic charging facilities. In combination to ITS and especially E-vehicle to infrastructure (V2I) technologies this flexibility of the EV demand will be utilized in order to efficiently allocate it during the valley period and hours with high RES production. Benefits from utilizing EV for DR can act as a financial incentive for the purchase of these vehicles and therefore the proposed approach fosters the decarbonisation of the transportation sector as well.

3. Maturity of the new technology: DAB protocol and first tests

The first step towards addressing pools of loads using Digital Audio Broadcasting is the development of a DAB protocol extension for smart grids applications. The requirements of such an extension (DAB+) are:

- The protocol extension should integrate into existing software from the transmitter side as multimedia objects. Reception and decoding should be possible using currently available digital broadcast receiver integrated circuits.
- The transmitted data is placed as encrypted data within the DAB data stream.
- The protocol is modular and new features can be added at a later time.
- The protocol has to support very low datarates (one DAB capacity unit, corresponding to approximately 1 kbit/s) and high reliability. This excludes for example any ascii based encoding such as XML.
- There is the possibility to transmit conditions and parameters.
- Despite a flexible and extendible structure, the protocol is always unambiguous and no freedom for interpretation by the receiver side exists.
- The data sent is intended to be read by electrical loads (or machines in general). It should be possible to distinguish between different classes of loads, but it is not intended to address individual loads only.
- There is the possibility to address loads only in a specific region or only for a specific timeframe.
- The system as a whole is robust to transmission errors in any case (even if no data is received at all).
- There is a way to guarantee that received data is free of errors.

The overall structure is as follows: The protocol itself is structured into data packages which are considered to be transmitted instantaneously. Each data package contains zero or several ”and-condition” fields, one or more parameter fields and zero or several ”or-condition” fields. Only if the receiving device meets all conditions of the "and-condition" fields and at least one condition of the ”or-condition" fields, it will regard the parameter fields. If a condition field is not known to a receiving device, it is considered as not fulfilled. If no "or-condition" fields are present, it will be interpreted as a valid condition. Newer data packages overwrite settings or data of older data packages if they are contradictory. It is legitimate that a package is not received due to data losses during transmission. A parameter field can contain data such as a price signal for example or a command code to lead to a behavioural change of the receiving device. If the field is unknown to the receiving device, it is disregarded.

And-Conditions: Each condition field consists of a key and a value pair which have to be defined in a table. These comprise, for example:

1. Location: Two lines of longitude and two lines of latitude which describe an area the receiving device has to be contained in.
2. Time-frame: A starting time and ending time which has to be fiTime. After the ending time, parameters are set back to default values.
3. Device class: A classification number of a device.

Parameters: Each parameter field is supposed to carry parameters or, more general: arbitrary data. Each Parameter fiis is separated into a key and a value field. Possible parameter fields are, for example:

1. Price: a price value.
2. Temperature: a reference temperature value.
3. Command: a command byte leading to some action of the receiving device.

Or-Conditions: These conditions are defined in the same way as the and-conditions, the difference is only in their interpretation. It is sufficient that a single or-condition is valid for the parameter fields to be regarded by the receiver, while all the contained and-conditions have to be met.

Full protocol: The full protocol contains a header with version and length infor-mation and cryptographically relevant bit. It uses 128 or 256 bit AES encryption and an additional 1 byte CRC. The and-conditions, parameters and or-conditions are aligned in this seemingly unlogical order to minimize the amount of necessary separation characters.

uGreen AG has already conducted the first feasibility study, demonstrating a DAB controlled switching of an electric load under laboratory conditions for the first time [11]. Data was transmitted in northern Switzerland for several weeks and processed by specially developed electric receivers which were attached to different electric loads. Control data was transmitted and received successfully. In Fig. 3, the results of the operation of a refrigerator with an attached DAB+ receiver and a wireless thermostat are presented. However, it is obvious that the operation curve of a heat-pump or an air-conditioning unit would be similar with Fig. 3. The green line is the energy-charging prices, which are transmitted through the DAB+ protocol. The blue line is the inner-temperature variation of the device. The down-hill slopes correspond obviously to the operation phase of the cooling system, whereas the up-hill slopes correspond to the idle phase of the cooling system. The command for the starting or the stop of the cooling system comes from the thermostat and the DAB+ receiver, which is programmed to take into consideration not only the inner-temperature upper and lower limits (here 6,5 and 4,5 ºC respectively), but also the cost-effective operation according to the price line. So, it is obvious that the down-hill slopes of the temperature appear almost concurrently with local minima of the energy prices.

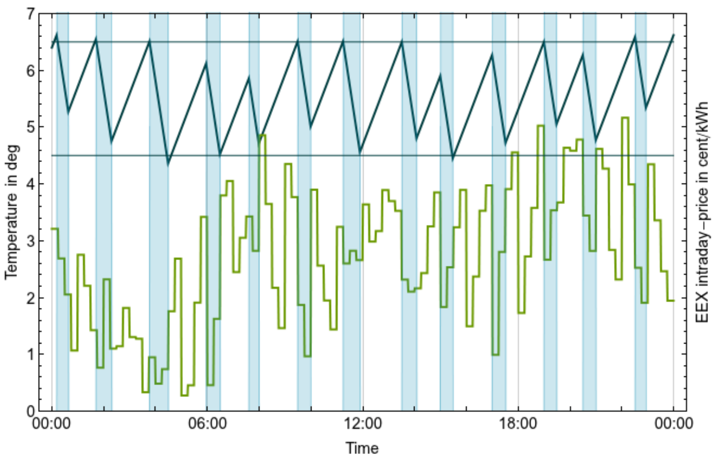

Fig. 3. Operation of a refrigerator with attached DAB+ receiver. The right-hand side prices are Phelix intra-day trading prices, 20 Aug. 2014 (data: epexspot.com) but could also be any arbitrary price signal.

4. Conclusions

The main objective of this paper is to present a new technology for the efficient energy management of electricity loads in buildings and cities in the framework of the smart grids trend. The new technology is based on the Digital Audio Broadcasting (DAB) standard and its interoperability with smart metering technology, that optimally utilize the Distributed Energy Resources (DER) penetration and energy price signals. DAB is a powerful and highly reliable technology and its integration with smart grid can enable secure contribution of distributed load in the power grid. The main idea involves the attachment of a DAB receiver to electric devices (from small household appliances up to EVs and PV plants) and the development of proper DAB interfaces and gateways to building automation systems, in order to enable DAB-based switching of electric loads and enable the implementation of the functionalities for smart metering systems. In this paper, the DAB+ protocol is described, enabling high cyber-physical security and support of virtual power plants that include a large scale of small electric loads (household appliances) and small DER units that are addressed using the DAB standard. The aim is for the proposed technologies to be installed in Athens in cooperation with ERT, in order to standardize the synergetic procedure that should be adopted between the different players (broadcasters, energy providers, DSOs, etc.).

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