5G Internet of Radio Light Services for Supermarkets

John Cosmas[1], Ben Meunier[1], Kareem Ali[1], Nawar Jawad[1], Mukhald Salih[1], Hong-Ying Meng[1], Jian Song[2], Jintao Wang[2], Min Tong[3], Xiaohong Cao[3], Xiao Li[4], Xun Zhang[5], Chuanxi Huang[5], Yue Zhang[6], Moshe Ran[7], Einat Ran[7], Eliron Salomon[8], Yoav Avinoam[8], Zion Hadad[9], Baruch Globen[9], Daniel Negru[10], Mathias Lacaud[10], Michael-Alexandros Kourtis[11], Harilaos Koumaras[11], Christos Sakkas[11], Li-Ke Huang[12], Rudolf Zetik[13], Krzysztof Cabaj[14], Wojciech Mazurczyk[14], Adam Kapovits[15]

Brunel University[1], Tsinghua University[2], Shanghai FEILO Acoustics CO.,LTD[3], Ledpcom[4], ISEP[5], University of Bedfordshire[6], MostlyTek[7], Holon Institute of Technology[8], Runel plc[9], Viotech[10], National Centre for Scientific Research Demokritos[11], Cobham Wireless[12], FHG-IIS[13], Warsaw University of Technology[14], Eurescom[15]
Email: john.cosmas@brunel.ac.uk

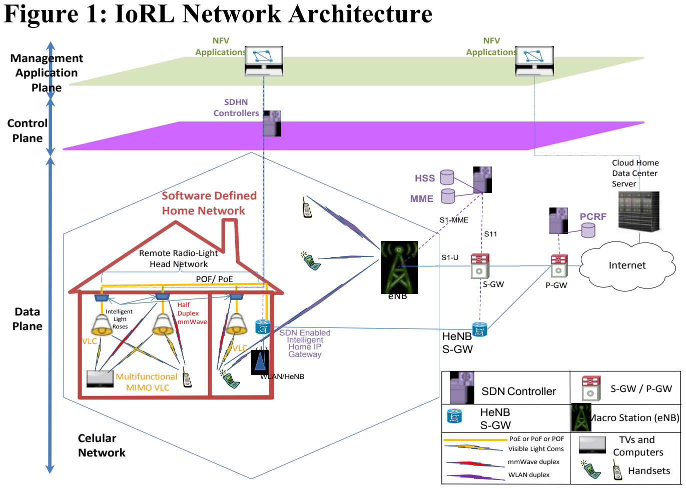
Abstract

In this paper we present a 5G Internet Radio-Light (IoRL) architecture for supermarkets that can be readily deployed because it utilizes unlicensed visible light and millimeter wave part of the spectrum and which is used to provide shoppers with accurate location, interaction, access to Internet and Cloud based services such as high resolution video on a Tablet PC. The paper describes the supermarket use cases, the user and functional requirements and the IoRL architecture.

Introduction

Internet of Radio-Light architecture is a 5G Radio-Light multi-component carrier, Frequency Division Duplex (FDD) broadband system for buildings, shown in Figure 1, consisting of a VLC downlink channel in the unlicensed THz spectrum and mm Wave up/downlink channels in unlicensed 30-300 GHz spectrum, which allows wireless communication networks to be deployed in buildings that can provide bitrates greater than 10Gbits/sec, latencies of less than 1ms, location accuracy of less than 10cm, whilst reducing EMF levels and interference, lowering energy consumption at transmitter/receiver and increasing User Equipment (UE) energy battery lifetime.

Figure 1: IoRL Network Architecture



The European Union funded IoRL research project's Software Defined Home Network (SDHN) Architecture, shown in Figure 1, not only allows network service providers to develop Security Monitoring, Energy Saving, Location Sensing, Network Slicing, Lights Configuration, Video and Network Transport Configuration and Network Security applications but also provides the means to locate network operations and management functions between the Intelligent Home IP Gateway (HIPG) and the Cloud Home Data Centre (CHDC) server in a configurable way to meet the different OPEX and CAPEX needs of different Mobile Network Operators (MNOs).

Furthermore it does not require MNO approval for deployment [1]. This step change in performance and flexibility is a very attractive solution for retailers since it will increase their ability to promote their brand and products thereby improving their profitability, which will incentivize them to raise capital to finance the upgrade of their building network infrastructure.

As there are 55,000 supermarkets [5] and 47,000 convenience stores [6] in the UK with a range of different sizes, a scalable architecture is required that is so simple that the ordinary electrician can install it and is so flexible that it can be easily expanded if required. This is roughly 1 supermarket and convenience store per 1000 people. Extrapolating these figures proportionally for EU, where there are 510 Million people then there are about 510,000 supermarkets and the same number of convenience stores and for China where there are 1.2 Billion people then then there are about 1.2 Million supermarkets and the same number of convenience stores. Furthermore an architecture that operates in unlicensed spectrum is required so that there are no restrictions to deploying it (i.e. does not require the permission of MNOs). This is a considerable sized market that is immediately available.

On the high street, price is no longer a competitive differentiator for retailers, rather, selling services, solutions and stellar shopping experiences is what is used to deepen emotional connections with shoppers and encourage consumers to shop longer, spend more money and stay loyal.

Mobile and digital communication technologies in social media are playing a bigger role in influencing shopping decisions, while traditional marketing continues to decrease, according to an advertising survey that was conducted between Feb. 23 and March 13, 2015, which polled more than 30,000 consumers in 60 countries throughout Asia-Pacific, Europe, Latin America, the Middle East, Africa and North America . Effective interactions generate excitement around a brand and keep retailers at the forefront of their customers' minds, and develop brand advocates in the general public [2].

Transparency throughout the supply chain food manufacturers and retailers are likely to embrace technology

978-1-5386-4851-3/17/$31.00 ©2017 IEEE

as well as available transparency tools to ensure their brands are accurately represented [3]. Additionally, utilizing technologies like big data analysis to mine loyalty programs allows retailers to quickly identify product purchases and alert shoppers of food safety issues or product recalls. (SmartLabel, which access to detailed information about thousands of food, beverage, personal care, household and pet care products; Shopwell, which finds healthy and nutritious alternatives to your favorite foods with highly personalized health scores on everyday grocery store products; and OpenLabel, which is a consumer-facing mobile platform that puts a public comment space on the barcode of every product) [4]. Furthermore personalization is enabled by Big Data and analytics, allowing more personalized grocery shopping experiences, which in turn could translate into increased sales and repeat visits by loyal customers is the focus of retailers.

Use Cases

This section presents supermarket use cases each one of which is a list of actions defining the interactions between a user and a system to achieve a goal.

Preparing a Shopping List

A customer downloads through a secured link IoRL "Smart Shopping Cart" (SSC) application on his/her smart phone where part of the procedure is providing a credit card account and uses it to prepare a shopping list. If a customer has not already prepared a shopping list, he can search on the SSC for his relevant products and where they are at the shop. This shopping list on the SSC could be synchronized with smart refrigerator.

(a) SSC on Trolley (b) Close up of SSC screen

Figure 2: SSC from IoRL partner Ledpcom

(a) Shopping Guide (b) Advertisements

Figure 3: Smart Phone with SSC App from IoRL partner Ledpcom

Store Guide and Route from Shopping List

A customer enters the supermarket and takes a Smart Shopping Cart (SSC), shown in Figure 2. SSC acknowledges the customer arrival on his smart phone, where his shopping list is written on, and is synchronized automatically with the SSC. If the customer is using a basket instead of a trolley, then the SSC App on his phone can be used, as shown in Figure 3.

The SSC calculates the relevant route for the customer and also, according to the things written on the list, can offer relevant content (promotions, reviews, recipes and other suggestions). If a product is missing the system can notify the customer and offer relevant alternatives.

The supermarket will launch an app which will be synchronized with the shopping list on the phone of the user. It can notify in advance if there are any products that are missing from the shop that the customer wrote on the list.

Highlighting Product Features on Shelves

While reaching the location of a food item, the SSC will be opened and highlight key features relevant to the product being selected, such as nutritional content e.g. the amounts of energy, fat, carbohydrates, fibre, protein and salt; by swiping the product barcode with the Smart Phone camera.

Monitoring Baby in the Nursery

Often in Supermarkets there is a crèche or nursery for children to play whilst their parent is shopping. While doing the shopping there is real time video monitoring of baby in the onsite nursery for children.

Viewing Cartoons for Children on Shopping Cart Chair

Often in Supermarkets the shopping cart has a chair for children to sit on whilst their parent is doing the shopping. While doing the shopping a cartoon film is streamed to the SSC to keep the child on its chair happy.

Virtual Shopping for the Disabled via the Carer

If a disabled customer is sitting in the coffee shop/ restaurant on site or at home and a carer is doing the shopping for them then the carer can communicate with the disabled person by video to help the disabled customer make the right purchasing choices.

Promoting the Sales of Products

The SSC, according to the products already placed in the SSC, can offer relevant recipes to the customer for cooking the selected item and then the SSC provides the customer with the choice of purchasing the other items required for the recipe combined with video cooking instructions, recommendations and reviews.

In Shop and Personalized Advertisements

Digital signage is used as a commercial based information guide, showing of current sales and offerings around the supermarket, whereas personalized advertisements are streamed on individual customer's screens around shop while shopping.

Rogue VLC Transmitter and Denial of Service Attacks

The analysis of initial system design and supermarket use cases reveals various potential security threats, from which two are most interesting are rogue VLC transmitter placement and DoS disruptive attacks. In the first scenario, an attacker places VLC transmitter which sends malicious code infecting

978-1-5386-4851-3/17/$31.00 ©2017 IEEE

supermarket clients` devices. In the second scenario an attacker leaves the device in the supermarket which interrupts VLC communication thus preventing e.g. automatic charge at the end of shopping.

Checking Out

The SSC is equipped with barcode reader (or similar) which sums up the purchase. When finished with the shopping, the customer just walks out from the supermarket and the system will charge his credit card/ bank account without the need to stop by at the cashier.

To exit the system, and make sure that the SSC is put back, the customer is reminded through SSC and gets a navigation route to return it back to its right place.

User Requirements

Stakeholders	Super Market
Shopper	<u>**Services**</u>: Smart Shopping Cart App; In-store Guidance Routing Service App; Promotions, Reviews, Recipes and other suggestions App; Stock Status and Alternative Foods Service; Nutritional Content Service; Video Nursery Monitoring app, Cartoon Film app, Internet Video Conference Communications, Recipe Information app; Advertisements app, Checkout and Payment Service. <u>**Products:**</u> Smart phone with camera, Smart Shopping Cart Tablet, Barcode Decoder.
Shop Management	<u>**Services:**</u> Customer Acknowledgement Server, In-store Guidance Routing Service, Promotions, Reviews, Recipes and other suggestions Service, Stock Status and Alternative Foods Service, Nutritional Content Service, Video Nursery Monitoring Service, Cartoon Film Service, Recipe Information Service, Advertisement Service, Checkout and Billing Server, Rogue VLC Transmitter and Denial of Service Attack Prevention Service. <u>**Products:**</u> Server, Tablet.

System Architecture

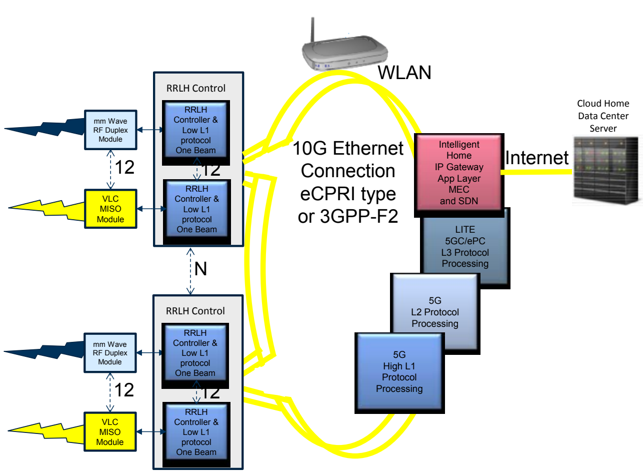


Figure 4: RRLH Architecture with External WLAN

The IoRL building network architecture uses a 10G Common Public Radio Interface (eCPRI) ring Ethernet [7], which easily allows the scalable addition of as many RRLHs as required and where the functional split between the RRLH Remote Unit and the Central Unit in the Physical Layer 1 can be at splits A, B or C on the protocol stack, as shown in Figure 5. The eCPRI Ethernet ring can be looped from room to room in a building from one RRLH to another in a similar way to the electric light circuit in a home. Each RRLH controller can support up to 12 mmWave antennas or VLC LEDs.

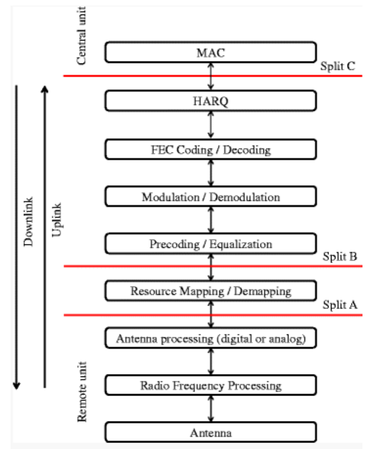


Figure 5: eCPRI Functional split options

As there is a limited amount of space available in Light Rose housing within which the VLC and mmWave RRLH is housed, the concept of Network Function Virtualisation (NFV) is adopted to off-load the complexity of the upper layer protocol processing of the communication systems required in the RRLH onto the CHDC or Intelligent HIPG. This complexity consists of Network Layer 3 and MAC Layer 2 processing and network functions such as Deep Packet Inspection, Caching, Firewall, Watermarking and Transcoding. The high level 1 Protocol processing is likely to be at Split B and further splits within the RRLH may be set at split C.

VLC DC-OFDM modulation is used which is compatible with the radio of the New Radio 5G frame formats. The bandwidth of the VLC LEDs can range between 20 MHz to 100 MHz depending on the quality of the LEDs lights used, which means that subcarrier spacing of up to 60 kHz from the 5G New Radio (NR) frame formats [8] can be used depending on the LED available bandwidth, as shown in Figure 6, potentially providing maximum downlink bit rate of 400M bits/sec. The similar 5G NR frame format can be used for the TDD mmWave channel operating in 60 GHz unlicensed spectrum thereby providing uplink bit rates ranging from 40M to 240M bits/sec and downlink bit rates ranging from 80M to 320M bits/sec, depending on the TDD frame type, as shown in Figure 7.

Subcarrier spacing [kHz]	3.75	7.5	15	30	60*	120	240	480	960
Symbol duration [us]	267	133	66.7	33.3	16.7	8.33	4.17	2.08	1.04
Nominal CP [us]	19	9.4	4.7	2.3	1.2	0.59	0.29	0.15	-
Nominal max BW [MHz]	5	10/12	20/25	40/50	80/100	160/200	320/400	640/800	1280/ 1600
Max FFT size	2048	2048	2048	2048	2048	2048	2048	2048	2048
Min scheduling interval (symbols)	7	7	7	7	7	14	28	56	120
Min scheduling interval (slots)	1	1	1	1	1	1	2	4	8
Min scheduling interval (ms)	2	1	0.5	0.25	0.125	0.125	0.125	0.125	0.125

Figure 6: Candidate 5G New Radio (NR) Frame Formats

978-1-5386-4851-3/17/$31.00 ©2017 IEEE

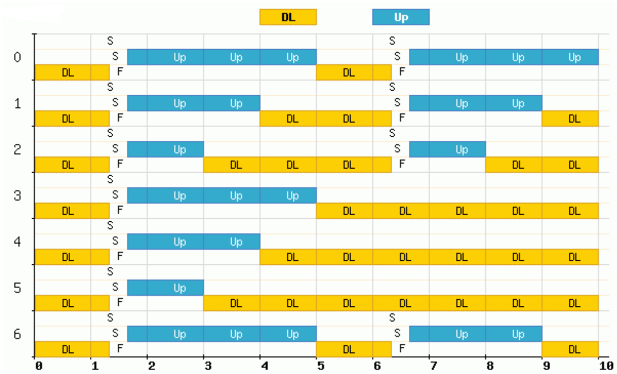


Figure 7: LTE TDD Frame Types

MISO diversity is used in the downlink where the same data to be transmitted from different mmWave antennas / VLC LEDs by the RRLHs at the same time thereby increasing reliability. In effect this creates a manmade multipath environment where if one or more of the light or mmWave paths is occluded then there is always the availability of the other paths to ensure continued communications, as shown in Figure 8.

SIMO diversity will be used in the uplink where the same data is received by different mmWave antennas at the RRLHs and maximum ratio combined higher up in the layered protocol thereby increasing reliability.

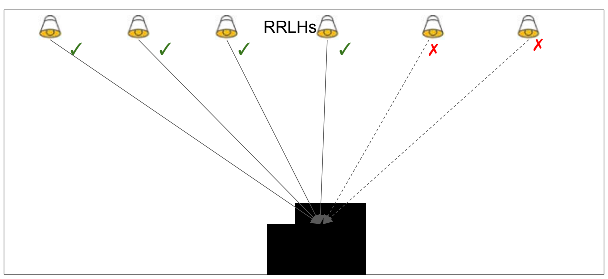


Figure 8: Downlink MISO and Uplink SIMO Diversity

In the case when all the paths are occluded, for example when someone conceals the Photo Diode (PD) receiver and mmWave antenna at the UE, then Multi Source (MS) streaming [9] is used to ensure that there is always the availability of another low capacity WLAN path for continued communications and continued synchronization with the streaming audio/video.

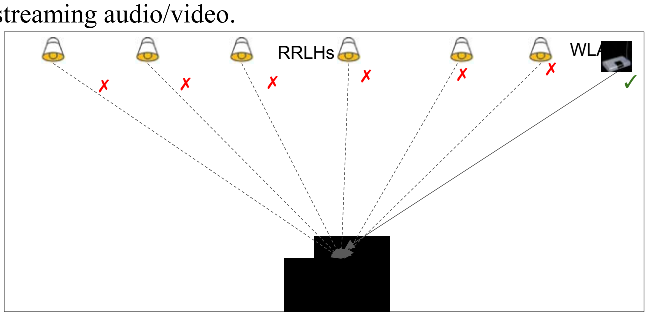


Figure 9: Multi Source Streaming to ensure connectivity

The Deep Packet Inspection NFV function is used at Intelligent HIPG to identify video streams and video transcoding is used to generate a lower quality MS Stream for the WLAN path to the UE, whereas the original higher quality SHDTV stream is transmitted by the broadband radio-light network. A Software Defined Network (SDN) forwarding device in the Intelligent HIPG is used to route these higher and lower quality video streams to RRLHs and WLAN. At the UE each of these streams is aggregatable with each other to produce a video better quality.

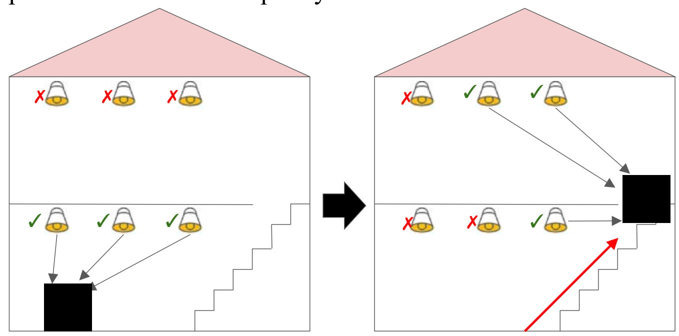


Figure 10: MS Streaming Intra Building Handover

The Reference Signal Received Power (RSRP) and Reference Signal Received Quality (RSRQ) of the outside radio network and the home radio-light network are measured by the UE and reported to the LTE's Mobility Management Entity (MME) to initiate a conventional inter (outside and building) network handover procedure.

Intra building handover between rooms or floors of a home network is performed at the MS Streaming application since its layer content consumption scheduler easily handles stream synchronization from multiple paths and multiple sources. .

In IoRL project, the positioning system consist two parts: VLC-based positioning system and mmWaves-based positioning system. A high positioning accuracy, which is less than 10cm, could be provided by combining both techiques.

The positioning system based on VLC uses visible light signals for determining the positioning of target where the signals are transmitted by lamps (RRLH) and received by light sensors (e.g. photodiode or camera), on the target UE as shown in Figure 11.

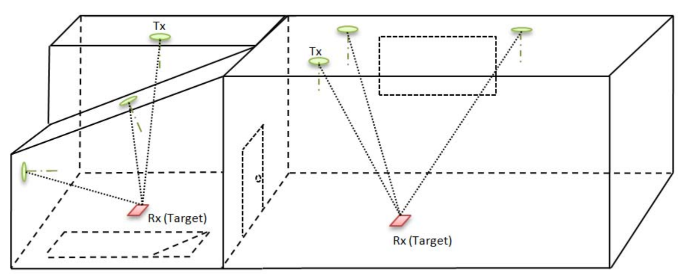


Figure 11: General scenario for VLC IPS

VLC based indoor positioning system (VLC-IPS) uses visible light signals for determining the location of target, the signals are transmitted by lamps (e.g. LEDs) and received by light sensors (e.g. Photodiode or image sensor). Compared to others RF based positioning techniques, it has many advantages. VLC-IPS can be installed inexpensively since they utilize existing illumination systems with few modifications. It can be used in RF-inappropriate environments, like hospital, underground mines and gas stations. Another advantage of

978-1-5386-4851-3/17/$31.00 ©2017 IEEE

VLC-IPS is that there is less effect of multipath on visible light than on RF signal [10], so the position estimation could be more accurate. Then LED drivers modulate VLC signals for each LEDs which carry corresponding positioning information (e.g. OOK, PPM, OFDM and so on). The different LEDs signals could be distinguished by using multiplexing method (e.g. TDM, FDM and so on). Then VLC signals are transmitted by LEDs and received by the light sensor which is carried by the target. When VLC signals are received, a demodulator is used to extract the LEDs' information and a signal analyzer detects the signal strength and arrival time which encompases the distance information between transmitter and receiver. Once the target is located, the positioning information will be sent back to RRLH.

The positioning system based on mmWaves uses electromagnetic waves to determine the location of UEs. In contrast to the VLC based localization, the mmWave target is intended to be a transmitter in our IORL architecture. Multiple lamps (RRLH) located at a priori known positions receive its transmitted signal. The RRLH controller estimates location relevant signal parameters such as the round trip time of arrival, or the received signal strength. These estimates are communicated to the central unit which calculates locations of UEs. The mmWave based localization can benefit from the large absolute bandwidth of license free frequency bands. The majority of mmWave frequency bands that are deregulated by FCC for 5G communication systems such as 37-38.6 GHz, 38.6-40 or 64-71 GHz have an absolute bandwidth covering couple of GHz. The FCC/ECC license free 60GHz WLAN ISM band (57-66GHz) and the related standard 802.11ay exploit an absolute bandwidth even much larger. It can simultaneously span 8 GHz. Such frequency bands can provide excellent time resolution which may result in sub-decimeter localization accuracy. This accuracy corresponds to the vision suggested for 5G networks [11][12] and clearly outperforms accuracy of the commercial global navigation satellite system with its outdoor accuracy of about 5 meters, or the accuracy of indoor wireless local area network fingerprinting techniques which is about 3–4 meters [12].

Nowadays providing security of every newly designed system is natural and most often “security by design” principle is followed. This means incorporation of dedicated security mechanisms and solutions from the architecture design phase of the IoRL system. As suggested in the 5G PPP Phase 1 Security Landscape [13] IoRL system will be equipped with security monitor & management functions at the IHIPG, which will be able to detect such events. Moreover, due to availability of localization functions such hostile devices can not only be detected but also precisely located. Such security approach can help supermarket security staff to identify potential attackers as well as remove hostile devices.

Conclusions

A 5G Radio-Light system has been described that is so flexible that it can be easily expanded if required to support supermarket properties that vary in size from small to very large and that can provide sufficiently large bandwidth to support large number of shoppers in a building using broadband services. The architecture is sufficiently flexible to support the different dynamics of the changing identity of occupants and their varying duration of occupancy. It operates in unlicensed spectrum so that there are no restrictions to deploying it (i.e. does not require the permission of MNOs). The architecture that is so simple and similar to the electric light circuit in properties that it is expected that the ordinary electrician can install it in order to easily install it in a large number of properties. An appealing set of example use cases are presented of the type of broadband services that can be provided in supermarkets using IoRL technology.

Acknowledgments

The authors gratefully acknowledge the financial support of the EU Horizon 2020 program towards the Internet of Radio-Light project H2020-ICT 761992.

References

[1] John Cosmas, Yue Zhang, Xun Zhang, “Internet of Radio-Light: 5G Broadband in Buildings,” European Wireless 2017, Dresden, Germany, 17th – 19th May 2017.
[2] Nielsen N.V. “Global Trust in Advertising”, September 2015
[3] Gerhard Schiefer, Jivka Deiters, “Transparency in the Food Chain,” Universität Bonn-ILB, Germany, 22nd July 2013.
[4] James Mathewson, Mike Moran, “Outside-In Marketing: Using Big Data to Guide your Content Marketing” IBM Press, 13 Apr 2016.
[5] “Number of supermarkets in the UK now greater than pubs” The Morning Advertiser, 28-8-2011
[6] Fiona Briggs “Number of convenience stores in the UK remains stable, reports IGD”, Retail Times, 24/05/2016.
[7] J. Bartelt, N. Vucic, D. Camps-Mur, E. Garcia-Villegas, I. Demirkol, A. Fehske, M. Grieger, A. Tzanakaki, J. Gutiérrez, E. Grass, G. Lyberopoulos and G. Fettweis “5G transport network requirements for the next generation fronthaul interface” EURASIP Journal on Wireless Communications and Networking (2017) 2017:89, DOI 10.1186/s13638-017-0874-7
[8] Reiner Stuhlfauth “The road to 5G LTE-A evolution, Internet of Things and first 5G aspects”, ROHDE & SCHWARZ GmbH Workshop, Royal Berkshire Conference Centre, Reading, 12th November 2016.
[9] J. Bruneau-Queyreix, M. Lacaud, D. Negru, J. Batalla, and E. Borcoci, "MS-Stream: A Multiple-Source Adaptive Streaming Solution Enhancing Consumers Perceived Quality," in IEEE Consumer Communications and Networking Conference (CCNC) - Best Demo award, 2017.
[10] Wenbo Ding and Fang Yang and Hui Yang and Jintao Wang and Xiaofei Wang and Xun Zhang and Jian Song. A hybrid power line and visible light communication system for indoor hospital applications, Computers in Industry, Vol: 68, pages: 170-178, 2015.
[11] R.E. Hattachi, J. Erfanian, 5g white paper, Next Generation Mobile Networks Alliance, 2015
[12] P Zhang, J Lu, Y Wang, Q Wang, „Cooperative localization in 5G networks: A survey“,ICT Express, Volume 3, Issue 1, March 2017, Pages 27-32
[13] P. Bisson, J. Waryet, al, " 5G PPP Phase1 Security Landscape", 5G PPP Security Group White Paper, 9 June 2017

978-1-5386-4851-3/17/$31.00 ©2017 IEEE