European H2020 Project WORTECS Wireless Mixed Reality Prototyping

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Abstract —This paper presents European collaborative project WORTECS objectives and reports on the development of several radio and optical wireless prototypes and a demonstrator targeting mixed reality (MR) application. The aim is to achieve a net throughput of up to Tbps in an indoor heterogeneous network for the MR use case, which seems to be a high throughput "killer application" beyond 5G. A special routing device is associated with the demonstrator to select the most suitable wireless access technology. Post introduction to the project, an overview of the demonstrator is presented with details of the current progress of the prototypes.

Index Terms—Optical wireless communication, fiber wireless fiber, radio, mixed reality, heterogeneous network

I. INTRODUCTION

The wireless data traffic is growing exponentially. Fig. 1 shows that by year 2024, the mobile data traffic per month is expected to surpass 100 Exabyte [1]. Much of this traffic will be for indoor data services. This exponential growth has led to a “spectrum crunch” in the lower frequency unlicensed bands, leading to growing interest in THz and Optical frequency bands. While 5G technologies will use the sub 100 GHz millimetre bands, the use of THz and Optical regions of the spectrum will be required for wireless systems beyond 100 Gbps.

Additionally, the nature of wireless services is also evolving with the rapid increase in the number of devices and new image based services. A new generation of displays, with the ability to create mixed reality (MR) environments, is available. MR places significant demands on bandwidth, latency, positioning and mobility, which are the main challenges that the project WORTECS aims to address.

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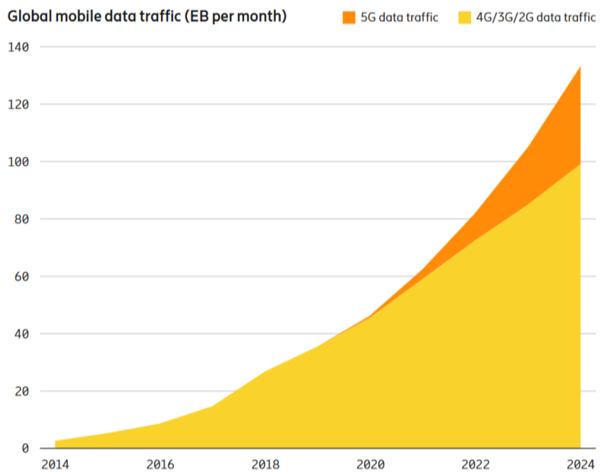

Fig. 1. Global mobile traffic (montly Exabytes).

II. WORTECS PROJECT PRESENTATION

The European Commission (EC) WORTECS project (Wireless Optical and Radio TErabit CommunicationS), addresses the “Networking research beyond 5G” research topic, outlined in the call of the Horizon 2020 (H2020) European Work Programme 2016-2017 [2]. This is a 3 years duration project started in September 2017. The scope of the project addresses novel demand-attentive and cooperative-access networking in order to combine the wireless technologies to achieve the ultra-high data rates.

The primary challenge addressed in the project is the development of a system able to deliver ultra-high throughput (up to Tbps). It will also meet stringent low latency and positioning requirements to address not only the anticipated end-users traffic demands after the 2020 time frame, but also the potential new and currently unknown demands that may arise as a consequence of new ways of using wireless communication networks in the future.

Key conceptual elements to be investigated, enabling such low latency and positioning requirements, include innovative network protocol and new signal processing algorithms.

The challenge will be illustrated by MR example use case [3]. The MR market is set to be huge. Market projections vary but it is agreed on two things: the market will be worth billions, and it will generate exponentially increasing revenue [4], [5] and [6].

In order to anticipate the next generation of Head Mounted Display (HMD), we estimate that the MR wireless solution should support at least a bandwidth of 100 Gbps/user (ideally>200 Gbps per user) in order to reduce or bypass the video compression and respect a maximum of 3 ms round trip delay.

Moreover, as MR experience will become multi-user, the WORTECS demonstrator has to support multi-channel to stream a dedicated rendering to each user navigating within the MR system through each HMD. The last WORTECS objective is dedicated to a precise positioning.

WORTECS consortium addresses these requirements thanks to the experience of its partners. WORTECS brings several European industrial players (Orange, B-COM and Oledcomm from France, IHP from Germany, pureLiFi from UK) as well as academics (University of Oxford from UK and University of Las Palmas from Spain). The WORTECS concept will emphasize:

- High-density Optical Wireless Communications (OWC) and LiFi expertise provided by industry leaders Oledcomm (OLD) and pureLiFi (PLF).
- Ultra-high data rate infra-red expertise provided by Orange Labs and University of Oxford (OXF).
- Ultra-high data rate radio expertise provided by IHP and B-COM (BCM).
- A compelling VR application expertise provided by B-COM.
- Multi-technologies management led by IHP, Orange Labs, University of Las Palmas and B-COM.

III. WORTECS DEMONSTRATOR

A. *System Overview*

WORTECS demonstrator's fundamental goal is to replace the cables between the MR server and the HMDs with a wireless link. The first one is the uplink cable, which is a USB cable that carries the localization information from the HMD to the MR Server. The second one is the downlink cable, which is a video cable (HDMI or Display Port depending on the HMD used) that carry the MR scene from the MR Server to the HMD.

Fig. 2 shows how WORTECS will meet these capacity demands. For the version 1 (V1) demonstrator with October 2019 deadline, the different MR contents are built in the server MR1 to MR4 for HMD MR1 to HMD MR4 respectively.

The master MR server coordinates different MR servers through broadband Ethernet connections. Output video (HDMI 2.0 or Display Port 1.4) and input localization (USB 2.0/3.0 port) are converted (A) to Ethernet protocol (1 or 10 Gbps) before being sent to Heterogeneous Network (HetNet) card (B) with 1 Gbps Ethernet cable or 10 Gbps optic fiber. The HetNet card processes and selects the routing path based on HMDs destination address and link reliability via several Gbps Ethernet cable (C) for Optical Wireless Communication Access Point (OWC AP) and 10 Gbps optic fiber for Fiber Wireless Fiber (FWF AP) and Radio AP. From APs (OWC AP, FWF AP and Radio AP), data are then transmitted to different wireless prototype (D).

On the HMD side, data is received and sent wirelessly by the HMD OWC, HMD FWF and HMD Radio prototypes (E), and then the data is converted from Ethernet protocol to HDMI2.0/DP1.4 format and USB (F) to adapt to the HMDs. For V1 version, the Lighthouse [7] equipment provides localization and tracking of the HMDs. In this demonstrator, four users, who wear HMD VR1 to HMD VR4, have their avatars located and integrated in the same MR environment. Increasing the number of APs expands the coverage and potentially the MR scenarios diversities. More details are available in [8]

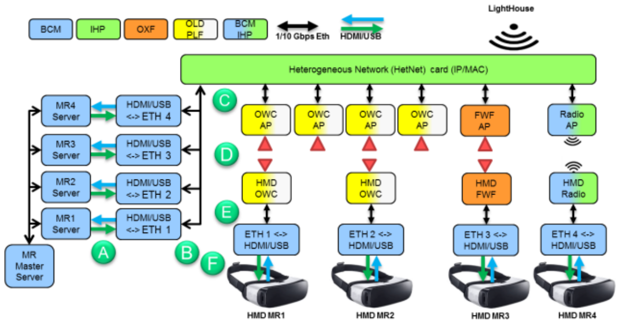

Fig. 2. WORTECS V1 demonstrator.

B. *Optical Wireless Communication (OWC) prototype*

The main objective is to define components to achieve a high throughput optical transmission system. For demonstration V1, this focuses on a high-density network that can provide more than 1 Gbps per user (full duplex) in a multi-user scenario with the potential to provide Tbps per room. The OWC systems provide bandwidth and user data rates beyond what is available in commercial systems today with a potential for substantial increase up to several Gbps on a point-to-multipoint configuration.

LiFi and Visible Light Communications (VLC) brought to the market in 2012, both Oledcomm and pureLiFi have VLC and LiFi products today. Even if technological problems concerning industrialization have been solved, there remain some challenges that must be addressed. Comparing the commercial systems with laboratory results [9], [10] and [11], a considerable difference in transmission rates can be seen. In this project, a proof-of-concept (PoC) working in realistic conditions is to be used as a demonstrator.

Oledcomm is working out the optical front-end for the prototype V1. Light emitters for OWC applications from microLEDs to blue lasers, have attracted a considerable amount of research in the recent years. For the current project, it is decided that an infrared laser [12] will be used based on the required power estimation from system modelling, which suggests powers of up to 100 mW. Moreover, an avalanche photodiode (APD) is used as the receiver photodetector, similar to the approach as in EC project OMEGA [13]. Optical wireless channel losses urge for the use of an adapted optical concentrator. Fig. 3 shows a design example for the optical receiver concentrator used to increase the Field Of View (FOV) and the gain. This Free-form concentrator (right) is compared with an off-the-shelf one (left).

At the digital baseband, designed and implemented by pureLiFi, OFDM is used due to its robustness against channel fading, and its spectral efficiency. Because of these advantages, OFDM modulation has been used in many high data rate applications and chosen in various standards. The OWC prototype uses a bandwidth of 200 MHz and OFDM with a DC bias (also known as DCO-OFDM). The transceiver architecture follows standard OFDM design with specification and parameters described as following:

- Scrambling based on IEEE802.11 standard,
- Convolutional Coding at rates 1/2 and 3/4,
- Bit interleaving based on the IEEE802.11 standard,
- Symbol mapping as BPSK, QPSK, 16QAM, and 64QAM, based on the available SNR,
- Framing block deals with the pilot insertion (to be used for channel estimation and synchronization) and impairment estimation and compensation,
- The IFFT size can vary between 64 to 256 points, and cyclic prefix can be set to 1/4, 1/8 or 1/16 or the IFFT size based on the channel condition,
- DAC is 12 bits resolution at 1 GSPS rate,
- ADC with 11 bit resolution at 1 GSPS rate.

The Rx OFDM architecture is generally the reverse of the Tx architecture. The channel estimation is performed during the detection process. The implementation board used for this PoC is Xilinx Zynq UltraScale+ MPSoC ZCU111 FPGA board, with number of suitable peripherals and interfaces for MR use case.

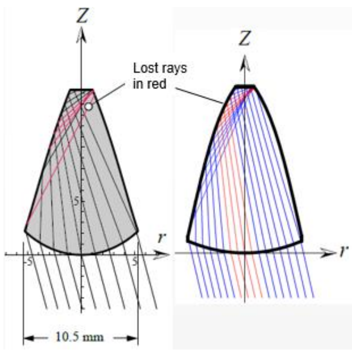

Fig. 3. Parabolic Compound (off-the-shelf) and Free-form concentrator design example.

For the V1 version, MAC layer used in this design is a modified version of the 802.11 PCF mode. The main distinction is that the MAC provides full-duplex operation. The full-duplex operation is enabled by the separate wavelengths used for the downlink and uplink. It is notice that the MAC is not compatible with non-PCF stations. All the frame types and structures are the same as 802.11a, while the frame can support up to 16 stations connected to the access point.

C. Fiber Wireless Fiber (FWF) Prototype

Tbps data rates can now be achieved in optical fiber systems, and wireless infrared links based on these technologies is a growing research area. Typically, light from an optical fiber is collimated to free-space, which propagates as a narrow beam (the wireless link), and is then coupled back down a fiber.

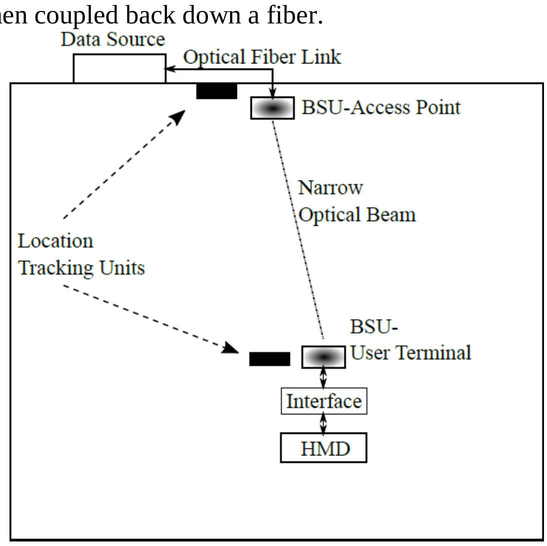

Fig. 4. A Generic FWF link setup in an indoor environment.

Fig. 4 shows a FWF setup in a generic form, where a beam steering unit (BSU) and location tracking unit is located at both the AP and the user terminal (UT). The wireless link is transparent, potentially bidirectional, and does not need optoelectronics interfaces. In order to provide sufficient network coverage, the narrow-beam FWF links rely on beam steering, localisation and tracking of the UTs.

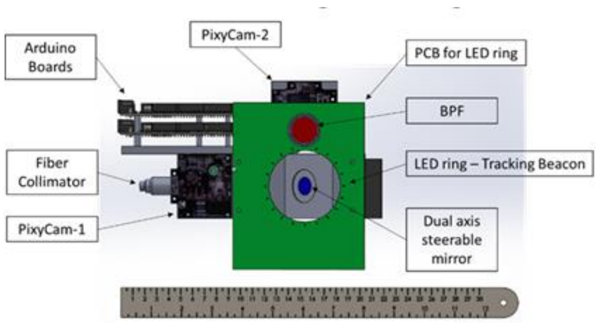

Fig. 5. Combined beamsteering and location tracking FWF system.

Ultrafast indoor OWC demonstrations have been reported over FWF link geometries [14] and [15]. And recently, University of Oxford in collaboration with University College London achieved both ultrahigh data rates (400 Gbps) and wide coverage [16] and [17]. These demonstrations incorporated beamsteering units at both ends of the link with adaptive optics compensation [18]. These are the fastest wireless links (Radio or optical) demonstrated thus far, with practical indoor coverage. Fig. 5 shows a compact example FWF PoC housing design, which combines the wireless link optics with the location tracking unit. The overall aim is to provide point-to-multipoint FWF communication links achieving 1 Tbps with automated alignment capability.

D. Radio Prototype

The main wireless radio transmission objective is to propose innovative radio interface that allows the system to achieve high data throughput. Some innovative solutions will be used to achieve these objectives. First, the design of an RF radio front-end at 240 GHz is explored to be able to transmit with high frequency bandwidth as well as digital signal processing techniques such as advanced channel (de)coding scheme at high throughput or use of multi-antenna array for spatial stream multiplexing.

The first objective is to specify the first components that will be implemented for the V1 demonstrator based on 60 GHz RF front-end with at least 4 or 5 Gbps data rate transmission per user. The second demonstrator will integrate a 240 GHz RF front-end and a throughput of at least 10 Gbps per user is targeted.

For the V1 version, it is planned to use the unlicensed 60 GHz band spans from 57 to 66 GHz. Four channels with equal width of 2.16 GHz are defined. The target is to occupy channel bandwidth of 1.76 GHz to demonstrate MR communication. The antenna is intended to be integrated on chip in order to guarantee a stable and reproducible performance. The digital part of the radio is implemented on an FPGA boards. This is needed due to the available flexibility as well as the performance the new generation FPGA devices can offer. The FPGA itself does not have data converters and, therefore, additional analog-to-digital and digital-to-analog converters are used. The FPGA board (Fig. 6) is a proprietary board developed by IHP and known as digiBackBoard.

Fig. 6. The digiBackBoard from IHP.

E. Heterogeneous Network (HetNet) Prototype

Ten years ago, EC funded project, OMEGA [13], focused on Ethernet, WiFi and Power Line Communications (PLC) interoperability. The IEEE 1905.1 standard inherited the OMEGA concept and extended it to MoCA and other WiFi technologies in addition to other features including AP auto configuration, topology discovery and links metrics.

The IEEE 1905.1 [19] standard introduces a new sublayer 2.5 to support heterogeneous technologies, such as PLC or Wireless LAN, in home networks. This new abstraction layer sits just above the data link layer (see Fig. 7) and hides the diversity of MAC implementations. Further, the sublayer 2.5 can switch between these underlying MAC technologies to reduce latencies and increase throughput.

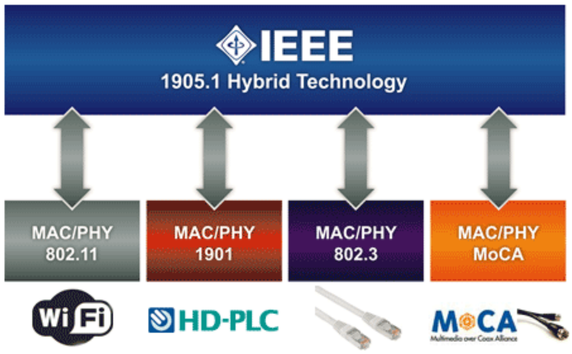

Fig. 7. IEEE 1905.1 standard - new sublayer on some MAC layer 2.

Then, the aim of another EC project named ACEMIND [20] was to provide new functionalities such as path selection and traffic monitoring. The WORTECS project targets a focus on radio and optical wireless technologies offering higher throughput and lower latency.

In WORTECS project, we follow the idea introduced in the IEEE 1905.1 standard and implement it on our hardware platform. However, the major difference is the user requirements. As depicted in Fig. 7, the IEEE standard considers only home networks with technologies support network throughput up to 1 Gbps. Due to the fact that we consider MR scenarios with 1000x higher network throughput; these new requirements cannot be satisfied with solutions introduced in the IEEE 1905.1 standard and various innovative approaches must be examined.

The major feature of Layer2.5 is to switch from one technology to another when it is needed and desired, to enable continuous data transmission to the user. For example, when the user moves inside a room it leaves the coverage of a certain optical or radio AP and should start receiving data from another AP. Further, in case of link degradation the Layer2.5-based switch selects another technology, with a better performance, for data transmission. These changes in technologies or access points are named handovers.

From the switch perspective, a handover is just an update of the internal switch table, which determines to which outgoing port frames are forwarded. The main challenge is to figure out when the handover (the update of the switch table) should happen and what is the next outgoing port for certain frame types.

In this project, we consider scenarios that require up to 1 Tbps throughput. Clearly, software implementations of Layer 2.5 cannot support such high throughput, since a single frame must be processed within a few nanoseconds. Moreover, current FPGA platforms work typically with a clock of hundreds MHz, so a single clock cycle is a few nanoseconds. Therefore, the FPGA implementation must process at least one frame in a single clock cycle. The only way to support such fast packet handling in parallel processing is to propose parallel hardware implementation to support frames processing within a few nanoseconds, with finally complexity and cost.

Another solution to support high-speed networking is an appropriate architecture of packet processing. Time critical operations, mainly packet forwarding, is done in the DataPlane (DP), and all other tasks in ControlPlane (CP). Basically, DP receives frames on a certain interface, looks up the forwarding table and sends them to a specific outgoing port. This forwarding table is updated by CP, which runs various algorithms to find a fast connection between network devices. Since DP includes time-critical operations, it requires a very efficient implementation, based on FPGA platform. The CP, however, does not have such challenging timing constraints and can be implemented as software to provide more flexibility.

Our target is to base our DP implementation on the Xilinx FPGA board VC709. The CP will be a software solution, running on a Linux-based PC, connected to the DP via an Ethernet port. This FPGA board supports four 10 Gbps Ethernet ports, with an option to add another four interfaces on an extra expansion card. Although this board will not support 1 Tbps network forwarding, due to limits in physical interfaces, we will use it to investigate various hardware solutions for the sub-layer 2.5 and carry out performance tests of FPGA-based packet process this extra abstraction layer.

IV. Conclusion and Outlook

This paper describes the main challenges that the WORTECS project has to address and the main solutions that are being investigated to implement optical and radio prototypes with heterogeneous network management targeting Tbps aggregated data-rates. First, it recalls the main requirements in term of throughput and latency for achieving MR transmission. The optical and radio architectures are presented by describing all the interfaces that have to be taken into account to interconnect all the equipment of the demonstration.

The result obtained from the V1 demonstrator in the B-COM smart cave will be available by October 2019. The next step will investigate solution for V2 demonstrator to achieve Tbps indoor communication by September 2020.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Olivier Bouchet is in charge of the WORTECS project management, Dominic O'Brien, Ravinder Singh, and Grahame Faulkner are in charge of the FWF prototype (see Section III.C), Mir Ghoraishi is leading the digital baseband development for the OWC prototype whereas Jorge Garcia-Marquez is in charge of the optical front end of this prototype (see Section III.B) and Guillaume Vercasson is working on the VR compression and application scenario. Finally, Marcin Brzozowski and Vladica Sark are developing the RF prototype and the HetNet (see Sections III.D and E).

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References

[1] Ericsson Mobility Report. (November 2018). [Online]. p. 18. Available: https://www.ericsson.com/assets/local/mobility-report/documents/2018/ericsson-mobility-report-november-2018.pdf

[2] European Work Programme - WORTECS H2020 - [Online]. Available: https://cordis.europa.eu/project/rcn/211056_en.html

[3] M. Badawi, T. Boggini, J. Royan, and C. Gallard, “Focus on Virtual Reality,” WORTECS deliverable D2.3a, 2017,

[4] Statista. Forecast augmented (AR) and virtual reality (VR) market size worldwide from 2016 to 2022 (in billion U.S. dollars). May 2018. [Online]. Available: https://www.statista.com/statistics/591181/global-augmented-virtual-reality-market-size/

[5] Statista. Virtual reality software and hardware market size worldwide from 2016 to 2020 (in billion U.S. dollars). 2017. [Online]. Available: https://www.statista.com/statistics/528779/virtual-reality-market-size-worldwide/

[6] Market Research Future, “Mixed Reality Market Research Report- Global Forecast to 2023,” January 2019,

[7] Valve Lighthouse SteamVR Tracking. [Online]. Available: https://enterprise.vive.com/us/

[8] Jorge Garcia-Marquez, *et al*, “Gbps wireless radio and Gbps wireless optical communications,” WORTECS deliverable D3.1, 2018.

[9] H. Chun, S. Rajbhandari, G. Faulkner, D. Tsonev, E. Xie, J. James, *et al*., “LED Based Wavelength Division Multiplexed 10 Gb/s Visible Light Communications,” *J. Lightwave Technol*, vol. 34, pp. 3047-3052, 2016.

[10] H. H. Lu, Y. P. Lin, P. Wu, C. Chen, M. Chen, and T. Jhang, “A multiple-input-multiple-output visible light communication system based on VCSELs and spatial light modulators,” *Opt. Express*, vol. 22, no. 3, pp. 3468-3474, 2014.

[11] C. W. Oh, E. Tangdiongga, and A. M. J. Koonen, “Steerable pencil beams for multi-Gbps indoor optical

wireless communication," *Opt. Lett*, vol. 39, pp. 5427-5430, 2014.
[12] J. X. C. B. Khalighi, "Double laser differential signaling for suppressing background radiations in FSO systems," in *Proc. 25th Biennial Symposium on Communications*, Ontario, 2010.
[13] European Collaborative Project OMEGA. [Online]. Available:https://cordis.europa.eu/project/rcn/85271/factsheet/en
[14] A. Gomez, K. Shi, C. Quintana, *et al*, "Design and demonstration of a 400 Gb/s indoor optical wireless communications link," *IEEE Journal of Lightwave Technology*, no. 99, pp. 1-8, 2016.
[15] C. W. Oh, F. M. Huijskens, S. Zo, *et al*, "36.7 Gbps spectrum-efficient indoor optical wireless system with beam-steering," in ECOC, 2014.
[16] H. Huang, G. Xie, Y. Yan, *et al*, "100 Tbit/s free-space data link enabled by three-dimensional multiplexing of orbital angular momentum, polarization, and wavelength," *Optics Letter*, vol. 39, no. 2, pp. 197-200, 2014.
[17] E. Ciaramella, Y. Arimoto, G. Contestabile, *et al*, "1.28 Terabit/s (32x40 Gbit/s) WDM transmission system for free space optical communications," *IEEE Journal on Selected Areas in Communications*, vol. 27, no. 9, pp. 1639-1645, 2009.
[18] Z. Ghassemlooy, "2 x 80 Gbit/s DWDM bidirectional wavelength reuse optical wireless transmission," *IEEE Photonics Journal*, vol. 5, no. 4, pp. 7901708–7901708, 2013.
[19] IEEE 1905.1-2013 - IEEE Standard for a Convergent Digital Home Network for Heterogeneous Technologies: https://standards.ieee.org/standard/1905_1-2013.html
[20] A. Kortebi, O. Bouchet, A. Mengi, H. Lucht, M. Brzozowski, O. Maye, P. Celeda, and J. Pazdera, "Convergent and reliable hybrid home networks," *IEEE DRCN*, March 2016.

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