Comprehensive Evaluation of an Antenna for TV White Space Devices

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Abstract: In this paper, an ultra-high frequency (UHF) antenna for TV white space devices (TVWSDs) is designed, fabricated and systematically tested. In addition to its radiation efficiency validation using a novel measurement approach, system performance of the antenna is comprehensively studied by integrating it onto different platforms, including a wideband spectrum monitor and a wireless communication client, and testing under realistic scenarios. The performance comparison with a commercial antenna is also performed to demonstrate the effectiveness and robustness of the in house-developed antenna. Overall practical and real-time performance evaluations show that the in-house developed antenna is a strong contender for TVWSDs.

Keywords: UHF antenna, TV white space, antenna measurement.

I. Introduction

TV white space (TVWS) refers to frequencies available for unlicensed use at locations where the TV spectrum is not occupied by the licensed broadcasting services. It can potentially be used for applications such as rural broadband, indoor communications and machine-to-machine communications [1]. In 2008, the Federal Communications Commission (FCC) approved unlicensed use of TVWS [2], and the Office of Communications (Ofcom) has also enabled license-exempt use of

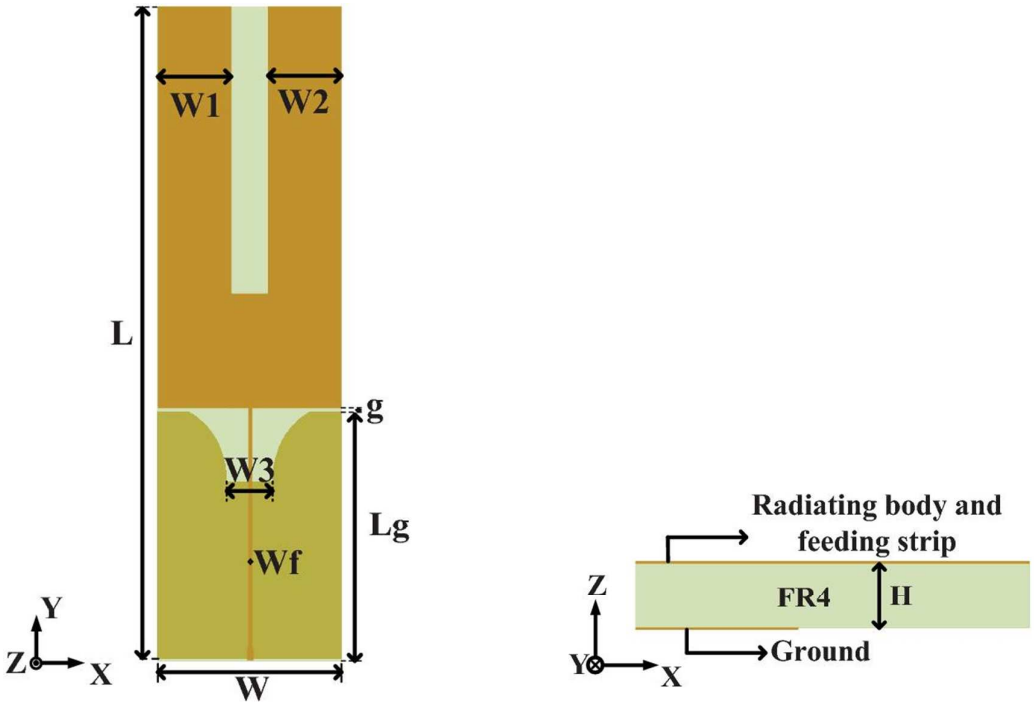
TVWS in the United Kingdom [3]. In the United Kingdom, the ultra-high frequency (UHF) TV band is over 470-790MHz, which is divided into forty 8MHz channels from channel 21 to channel 60.

Having over 50% bandwidth, the UHF TV spectrum is ultra-wideband (UWB) according to the FCC [4], and one or multiple idle TV channels are allocated to TVWS services dynamically through information exchanged with geo-location database [5]. Hence, UWB antennas are required for TV white space devices (TVWSDs) to operate on the TVWS. Additionally, antenna performance is commonly evaluated by measuring its properties in an anechoic chamber, while to quantify the loss of an antenna itself, its radiation efficiency is expected. Besides, system performance in realistic scenarios would be more convincing to appraise an antenna.

In this paper, an in-house developed UWB antenna is evaluated by measuring its radiation efficiency in a reverberation chamber using the modified two-antenna method. In addition, it is integrated onto both a wideband and a narrowband systems for realistic performance assessment.

II. Radiation efficiency measurement

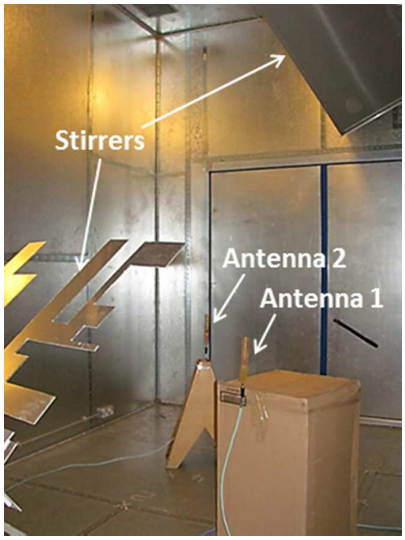
An UWB antenna illustrated in Fig. 1 for TVWSDs has been proposed and analysed in the previous work [6]. A U-shape radiator is printed on a 0.8mm-thick FR4 substrate and is fed by a microstrip line. At the other side of the substrate, a notch is cut on the ground whose edges are optimised to arcs to improve the impedance matching. The proposed antenna achieves -10dB impedance bandwidth from 470MHz to 884MHz, and it has an omnidirectional radiation pattern on the magnetic field plane. Detailed design and discussion can be found in [6].

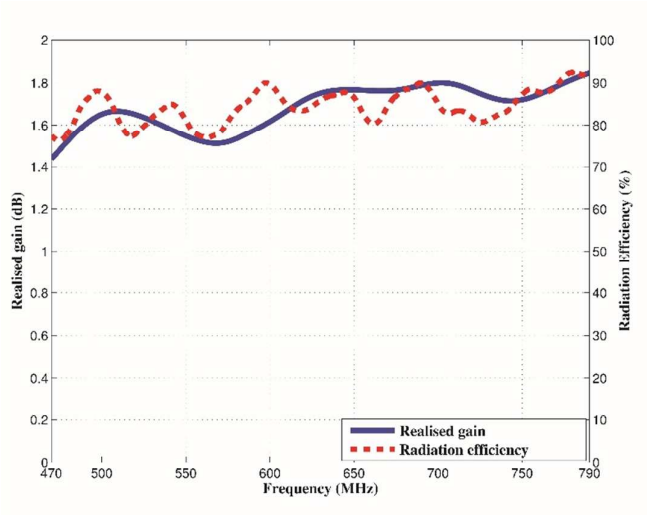


(a) (b)

Fig. 1 Geometry of the in-house developed antenna (a) top view and (b) side view (L=231mm, Lg =85mm, g =1mm, W =35mm, W1=W2 =14mm, W3= 6mm, Wf = 1.1mm and H =0.8mm).

Typical antenna properties including reflection coefficients, gains and radiation patterns are commonly measured in an anechoic chamber where reflections of electromagnetic waves are absorbed. Quantifying the loss of an antenna itself, radiation efficiency is another key property of an antenna, and it is a dominating factor for antenna performance in multipath environments [7]. However, measuring the radiation efficiency in an anechoic chamber is often difficult and inaccurate [8]. The traditional Wheeler Cap method measures narrowband radiation efficiency. By removing the need of any assumption on the antenna equivalent circuit, Johnston improved the efficiency measurement to ultra-wide range of frequencies, but this method is based on a variation of the physical dimension of the cap [9]. Reverberation chamber has been used in recent years for easy and accurate radiation efficiency measurement [10].





(a) (b)

Fig. 2 (a) Radiation efficiency measurement set up and (b) radiation efficiency and realised gain of the in-house developed antenna over the UHF TV spectrum.

In this paper, radiation efficiency is measured in a reverberation chamber using the modified two-antenna method [11], and duplicate antennas under test are placed in the chamber at the same time as Fig. 2(a) shows. The radiation efficiency can then be calculated based on (1), in which ω is the angular frequency, τ_{RC} is the chamber decay time and C_{RC} is the chamber constant $C_{RC} = 16\pi^2 V/\lambda^3$ (V is the volume of the chamber and λ is the wavelength). <·> represents the average value of S-parameters, and $S_{ab,s}$ is the stirred part of S-parameters.

$$\eta = \frac{<|S_{21,s}|^2>}{1-|<S_{11}>|^2}\sqrt{\frac{2C_{RC}}{\omega\tau_{RC}<|S_{22,s}|^2>}} \quad (1)$$

The radiation efficiency of the in-house developed antenna over the UHF TV spectrum is plotted in Fig. 2(b) together with its realised gain which is measured in an anechoic chamber using a common reference antenna methods [12]. According to Fig. 2(b), ranging from 1.4dBi to 1.9dBi, the realised gain reaches 1.7dBi in average over 470-790MHz. The radiation efficiency is between 76.2% and 92.4%, and hence most power delivered to the antenna is capable of being radiated. Both gain

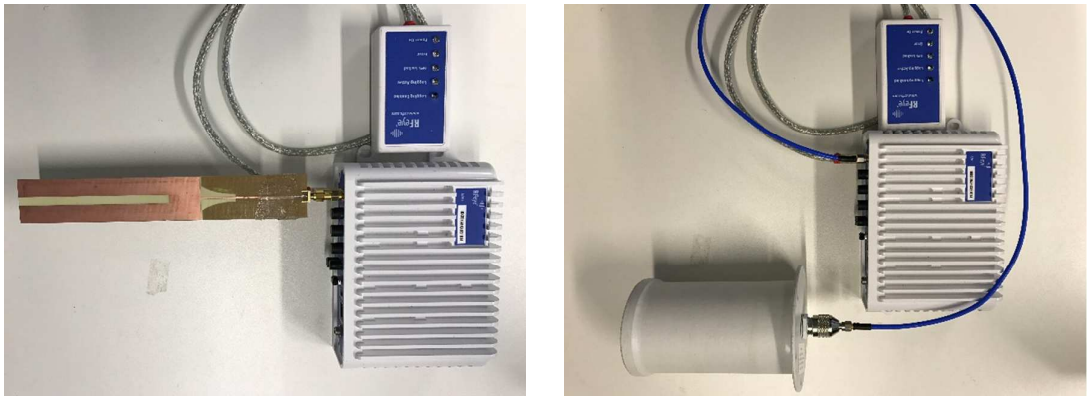
and radiation efficiency are uniform over the UHF TV spectrum, and the measurement results indicate that the in-house developed antenna provides stable and efficient services for TVWSDs.

III. Field trails

The in-house developed antenna is then integrated with wideband and narrowband systems, respectively to assess its performance in different practical applications.

3.1 Wideband spectrum sensing

To verify the in-house developed antenna is able to operate over the entire UHF TV spectrum, it is connected with a RFeye system provided by CRFS for intelligent spectrum monitoring [13]. The testing system consists of a RFeye node panel, a logger control box, a laptop with the RFeyeSite software installed and a USB memory stick.



(a) (b)

Fig. 3 (a) RFeye node with the in-house developed antenna and (b) commercial antenna.

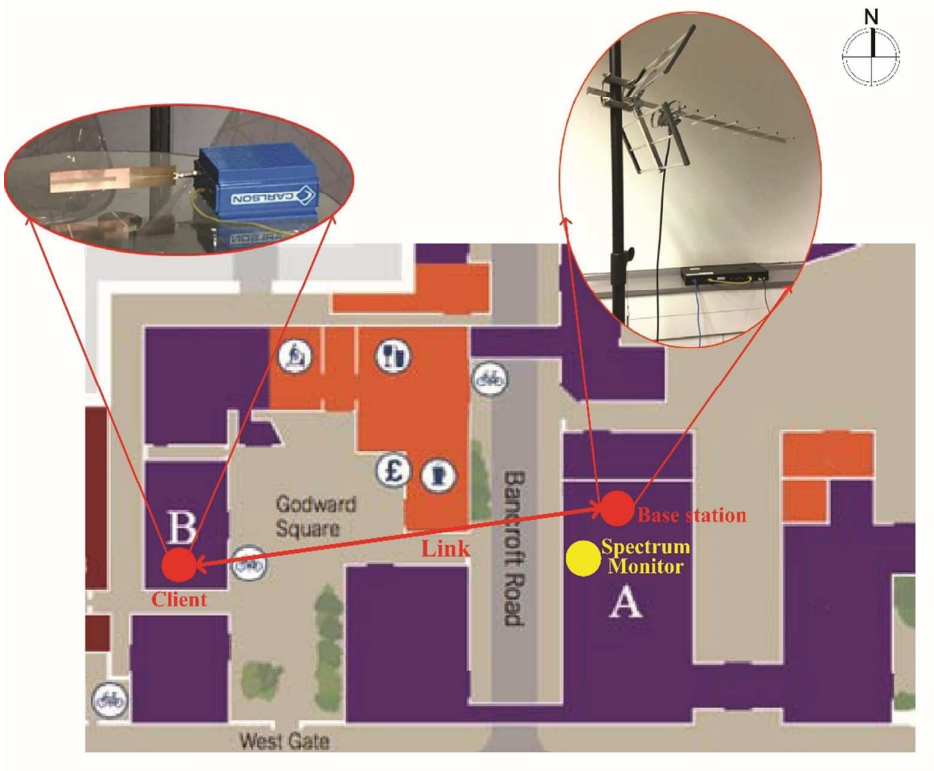


Fig. 4 Testing environments for spectrum detection and TVWS communication.

An antenna prototype is connected to the RFeye node as shown in Fig. 3(a). On the RFeysSite software, the start and end detection frequencies are set to 470MHz and 790MHz, respectively, and 320kHz (0.1% of the bandwidth of the UHF TV spectrum) is chosen for resolution bandwidth. When monitoring the spectrum, the whole system is placed at Room 353 of the Engineering Building in the Queen Mary University of London (QMUL) indicated on the testing environments given in Fig. 4. The measured data is export from the USB memory stick and plotted in Fig. 5. Using -90dBm as a signal intensity threshold, occupation statues of the UHF TV channels are given in Fig. 6.

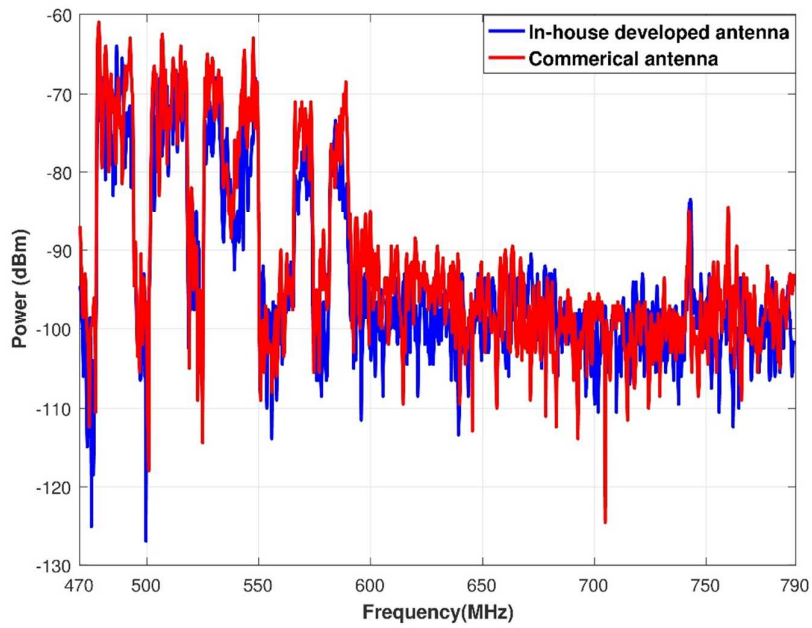


Fig.5 UHF TV spectrum detected by a spectrum monitor equipped with the in-house developed antenna and a commercial antenna.

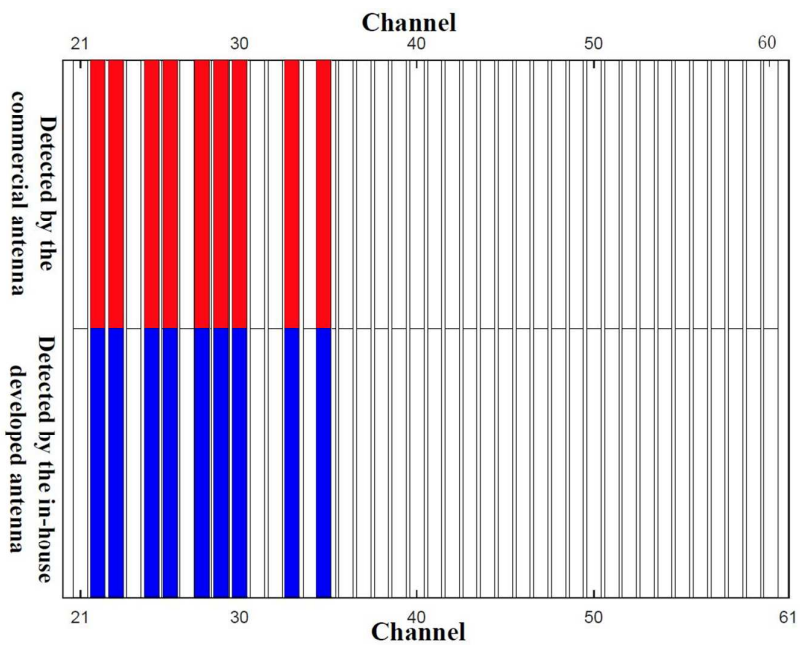


Fig. 6 Channel occupation of the UHF TV spectrum.

According to Fig. 5 and Fig. 6, the UHF TV channels from 36 to 60 are vacant, which may be resulted from few signal transmission above 600MHz or poor system performance of the in-house

developed antenna at high frequencies. Therefore, the spectrum is monitored again at the same location with same settings, but the antenna connected to the RFeye node is changed to a commercial one provided by the CRFS as illustrated in Fig. 3(b). The detected signal is also plotted on Fig. 5 for easy comparison with results acquired from using the in-house developed antenna. The two curves coincide well with each other, and mall discrepancies can be caused by variances of the noise at different time, and gain difference of the two antennas. Hence the in-house developed antenna performs well over the entire UHF TV spectrum.

3.2 Narrowband wireless communication

A TVWS spectrum license has been granted by the Ofcom for real-time wireless transmissions in the Mile End campus of QMUL, and a communication link on the TVWS is set up as illustrated in Fig. 4. The base station and its sector antenna pointing at northwest are placed on the third floor in building A. The base station is connected to the Ethernet to acquire transmission information and its transmitting power is 23dBm. Maximum gain of the directional sector antenna is 11dBi and its feeding cable has 1dBi loss. Client with the in-house developed antenna is on the second floor in building B. Distance between the base station and client is 127.5m, and there are two blocking buildings, some trees and a busy road between them. During communication, signals undergo reflection, fading and multipath interference due to people, office facilities, walls and trees.

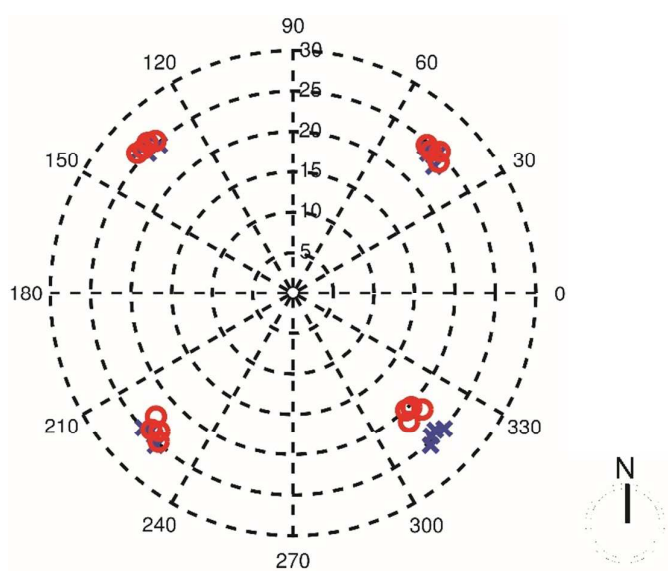


Fig. 7 Link SINRs with the in-house developed antenna facing different directions. SINR of uplink is noted by 'o' and that of downlink is noted by '+'.

Due to the complicated communication environment, signals arrive at the client are non-directed, and the communication quality is ensured by the high radiation efficiency of the in-house developed antenna. To observe the system performance comprehensively, the client is placed to make its antenna facing southeast, northeast, southwest, and northwest. Signal-to-interference-plus-noise ratios (SINRs) of both uplink (UL) and downlink (DL) are plotted in Fig. 7. Four sets of data is recorded at different times with the client antenna facing each direction to remove effects from environment variations, and data within a set is separated by small degrees to be distinguished. It can be observed from Fig. 7 that SINRs of both DL and UL have slight variances when changing directions of the client antenna.

Moreover, connecting a computer to the client, the Internet can be accessed through TVWS signals. An online application SPEEDTEST is used to monitor network speeds and the averaged DL and UL speeds are 9.5Mbps and 3.6Mbps, respectively. These measurement results correspond well to the omnidirectional radiation pattern, good realised gain and high radiation efficiency of the in-house developed antenna as analysed in Section II, and its satisfying performance in a wireless communication system is proved.

IV. Conclusion

An in-house developed UHF UWB antenna has been evaluated comprehensively by measuring its radiation efficiency and testing in realistic systems. Being integrated onto a spectrum monitor, UWB property of the antenna is verified through comparing the detected UHF TV spectrum with that detected by a commercial antenna. Measurements of a wireless communication under complicated environments with the antenna equipped at the client reveal that signals of a network established on TVWS are able to travel long distances and skirt obstacles. Therefore, the compact, low-profile and omnidirectional in-house developed antenna is promising for energy-efficient TVWSDs.

References

[1] Y. Gao, R. Ma, Q. Zhang and C. Parini, ''UHF Antennas for Machine-to-Machine Communications and Internet of Things,'' EuCAP 2016, Davos, pp. 1-3, Apr. 2016.

[2] Federal Communications Commission (FCC), ''In the Matter of Unlicensed Operation in the TV Broadcast Bands, Additional Spectrum for Unlicensed Devices Below 900 MHz and in the 3 GHz Band, Second Memorandum, Opinion and Order'', Sep. 2010.

[3] UK Office of Communications (Ofcom), ''Decision to make the wireless telegraphy (white space devices) (exemption) regulations 2015'', Dec. 2015.

[4] Federal Communications Commission (FCC), ''First report and order in the matter of revision of part 15 of the commission's rules regarding ultra-wideband transmission systems. et-docket. 2002: 98-153," Apr. 2002.

[5] Z. Qin, Y. Gao, M. Plumbley, and C. Parini, ''Efficient compressive spectrum sensing algorithm for M2M devices," GlobalSIP 2014, Atlanta, pp. 1170-1174, Dec. 2014.

[6] Q. Zhang, Y. Gao and C. Parini, ''Compact U-shape Ultra-wideband Antenna with Characteristic Mode Analysis for TV White Space Communications,'' AP-S/URSI 2016, Fajardo, Jun. 2016.

[7] P. Besnier, J. Sol, A. Presse, C. Lemoine and A.C. Tarot, ''Antenna efficiency measurement from quality factor estimation in reverberation chamber'', EUMC 2016, London Oct. 2016.

[8] G. Le Fur, C. Lemoine, P. Besnier and A. Sharaiha. "Performances of UWB wheeler cap and reverberation chamber to carry out efficiency measurements of narrowband antennas." IEEE Antennas and Wireless Propagation Letters, vol. 8, pp. 332-335, Sep. 2008.

[9] R. H. Johnston and J. G. McRory, “An improved small antenna radiation efficiency measurement method,” IEEE Antennas and Propagation Magazine, vol. 40, no. 5, pp. 40–48, Oct. 1998.

[10] C. L. Holloway, H.A. Shah, R. J. Pirkl, W. F. Young, D. A. Hill, and J. Ladbury, ''Reverberation chamber techniques for determining the radiation and total efficiency of antennas,'' IEEE Transactions on Antennas and Propagation, vol. 60, no. 4, pp. 1758-1770, Apr. 2012.

[11] Q. Xu, Y. Huang, X. Zhu, L. Xing, Z. Tian and C. Song, "A modified two-antenna method to measure the radiation efficiency of antennas in a reverberation chamber," IEEE Antennas and Wireless Propagation Letters, vol. 15, pp. 336-339, Jun. 2015.

[12] IEEE Standard Test Procedures for Antennas, IEEE Standard 149^{TM}-1979 (R2008), Dec. 2008.

[13] CRFS, ''RFeye Nodes''. [Online]. Avaliable: https://us.crfs.com/en/hardware/nodes/.