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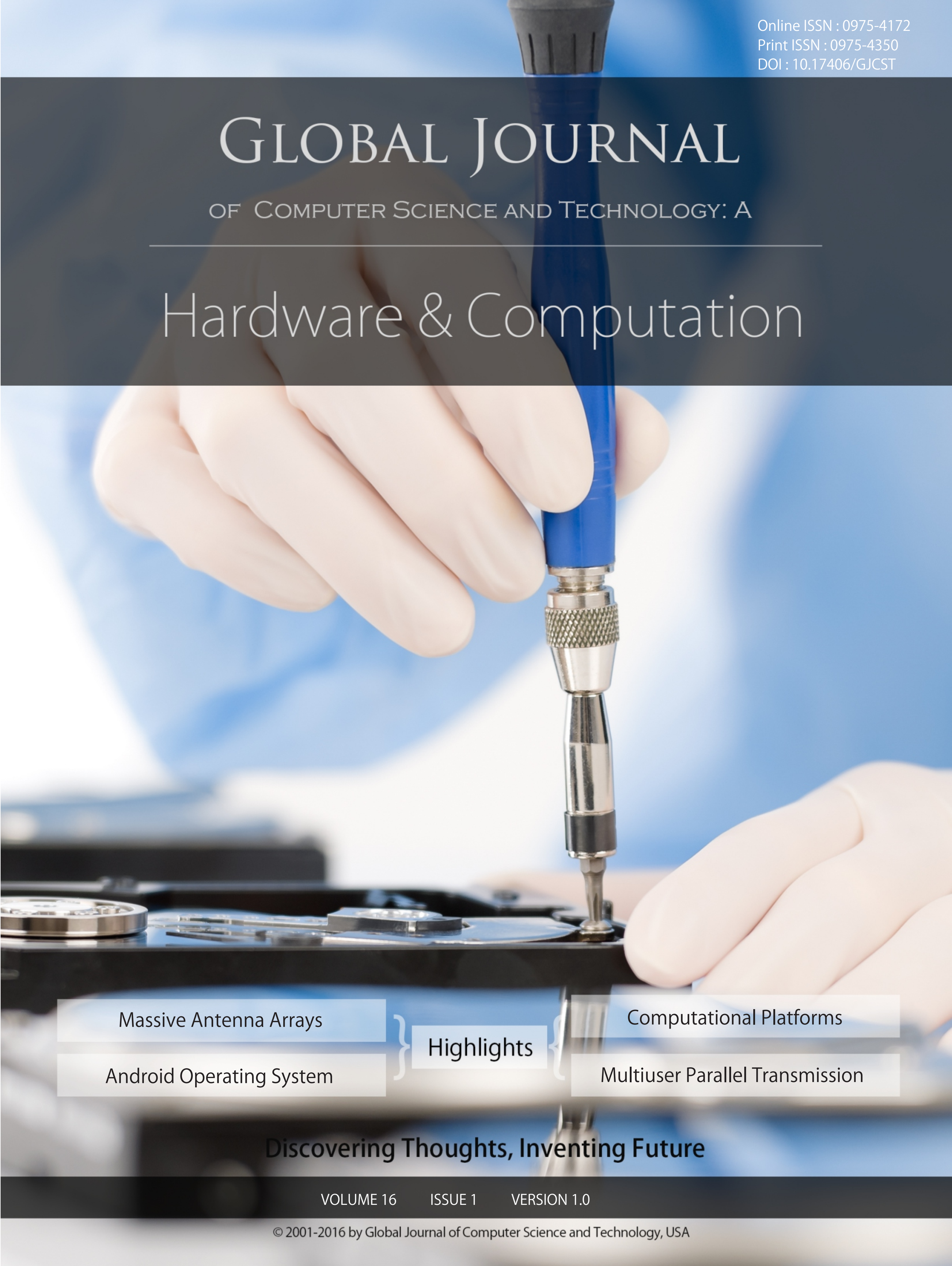
Hardware & Computation



Highlights

- Massive Antenna Arrays
- Android Operating System
- Computational Platforms
- Multiuser Parallel Transmission

Discovering Thoughts, Inventing Future

VOLUME 16 ISSUE 1 VERSION 1.0

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Performance Assessment of WhatsApp and IMO on Android Operating System (Lollipop and Kitkat) during Voip Calls using 3G or WiFi

By R.C. de Oliveira, H.M. de Oliveira, R.A Ramalho & L.P.S. Viana
Amazon State University

Abstract- This paper assesses the performance of mobile messaging and VoIP connections. We compared the CPU requirements of WhatsApp and IMO under different scenarios. This analysis also enabled a comparison of the performance of these applications on two Android operating system (OS) versions: KitKat or Lollipop. Two models of smartphones were considered, viz. Galaxy Note 4 and Galaxy S4. The applications behavior was statistically investigated for both sending and receiving VoIP calls. Connections have been examined over 3G and WiFi. The handset model plays a decisive role in CPU requirements of the application. t-tests shown that IMO has a statistical better performance that WhatsApp whatever be the Android at a significance level 1%, on Galaxy Note 4. In contrast, WhatsApp requires less CPU than IMO on Galaxy S4 whatever be the OS and access (3G/WiFi). Galaxy Note 4 using WiFi has always better performance than S4 in terms of processing.

GJCST-A Classification : *C.2.1, C.2.3*

PERFORMANCEASSESSMENTOFWHATSAPPANDIMOONANDROIDOPERATINGSYSTEMLOLLIPOPANDKITKATDURINGVOIPCALLSUSING3GORWIFI

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Performance Assessment of WhatsApp and IMO on Android Operating System (Lollipop and Kitkat) during Voip Calls using 3G or WiFi

R.C. de Oliveira [α], H.M. de Oliveira [σ], R.A Ramalho [ρ] & L.P.S. Viana [ω]

Abstract- This paper assesses the performance of mobile messaging and VoIP connections. We compared the CPU requirements of WhatsApp and IMO under different scenarios. This analysis also enabled a comparison of the performance of these applications on two Android operating system (OS) versions: KitKat or Lollipop. Two models of smartphones were considered, viz. Galaxy Note 4 and Galaxy S4. The applications behavior was statistically investigated for both sending and receiving VoIP calls. Connections have been examined over 3G and WiFi. The handset model plays a decisive role in CPU requirements of the application. t-tests shown that IMO has a statistical better performance that WhatsApp whatever be the Android at a significance level 1%, on Galaxy Note 4. In contrast, WhatsApp requires less CPU than IMO on Galaxy S4 whatever be the OS and access (3G/WiFi). Galaxy Note 4 using WiFi has always better performance than S4 in terms of processing.

I. Introduction

Instant messaging and VoIP (voice over IP) for mobile phones are growing importance in the contemporary society. The instant messaging (IM) is a set of communication technologies used for text-based communication between two or more participants usually over the Internet [2], [8]. In particular, IM in mobile phones is becoming a worldwide fever [12], [1], [10]. In performance evaluation of electronic devices is commonplace to build a base for comparison (baseline, [4]). Usually this database is constructed by applying tools that collect performance metrics (e.g. CPU, disk, memory and network statistics). Through such a baseline, the analyst can pinpoint where the drawbacks are, and carry out performance adjustments so as to improve the throughput of a given application. The choice of performance metrics, how performing data collection, and data analysis are common steps of performance evaluation. We conducted a performance assessment of the WhatsApp as compared with the performance of IMO through 3G and Wifi, on different operating systems Android [15], [5]. The performance of such applications remains rather unexplored both from the theoretical viewpoint as well as in academia. See [3] for a comparison between WhatsApp and standard SMS.

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II. Materials and Methods

The analysis delimited in this study is just VoIP on smartphones. The analysis carried out in this study would be limited to monitoring the processing when instant messaging or voice call applications. The universe of study of this investigation is characterized by the scope of operation of mobile devices. The field of study covered the transmission by wireless LAN (WiFi) or 3G networks [14]. It was not taken into account the coding, nor programming logic or source code of applications. Android OS is a multitasking operating system for for mobile devices, including smartphones and tablets, which have different versions [9], [5]. The main purpose is the analysis of cross-platform instant messaging for smartphones, viz. WhatsApp and IMO, with versions of Android, KitKat and Lollipop. For the present experiment we used an analysis tool, techniques measurements and statistical methods. The scope of the study was carefully designed to avoid interference from outside or assumptions that were not linked to the analysis. Moreover, for the proper background collecting of logs on mobile applications is essential to select software that is able to perform the performance data capture. Sampling tests were performed by selecting an appropriate tool to collect specific logs. Our choice fell upon the Little Eye and thereafter it was possible to analyze the resources and ways processing [7]. Test devices were Samsung Galaxy S4 (S4) and Samsung Galaxy Note 4 (N4), both with different hardware and which have been installed Android. To build the environment, it was also required to install and configure a wireless network as well as the availability of carrier chip with 3G transmission. The tests involved the following steps: (i) Install the OS on the test device; (ii) Set up, install and operate software for testing; (iii) Set up, install and operate application software; (iv) Perform the collection of logs; (v) Handling the collected data; (vi) statistically analyze the data collected. “Little Eye” is a performance analysis and monitoring tool that can help to identify and fix bug in an application with Android versions from 2.3 [7]. It is a tool

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that supports metrics related to CPU, network resources, RAM, disk space, GPS and battery consumption. Its main features are:

- *Measure:* measuring the performance of applications gathering information about each feature used the device generating detailed statistics for each resource;
- *Analyze:* It brings information about the background of the data collected creating graphs and statistics for analysis;
- *Optimize:* Suggest improvements in resource consumption by optimizing the operating system.

For tool installation the following requirements is necessary:

Java JRE or SDK - V 1.6 + (Java 6 or higher) and Android SDK;

USB debugging is enabled on the phone;

Set the device to connect to as "camera (PTP)" rather than "media device (MTP)";
Test device drivers are required when using Windows OS.

With everything set (hardware and software environments), Little Eye starts. Once started, it loads applications under test on the device. After listing all applications, simply select the application to be tested (WhatsApp or IMO), and then configure the measurements of

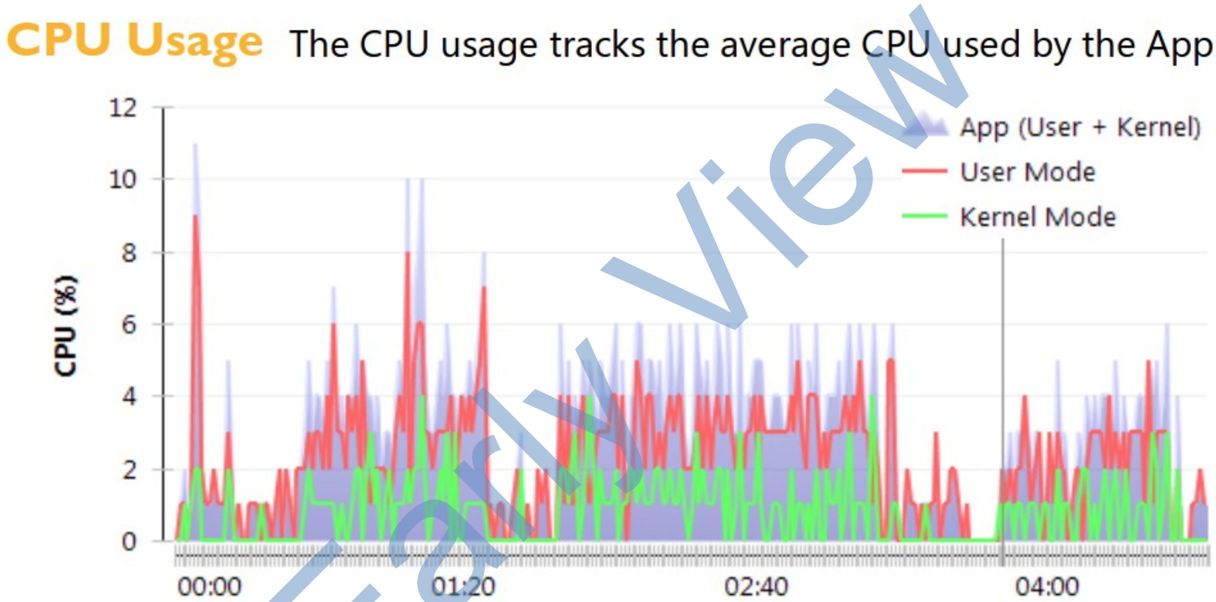


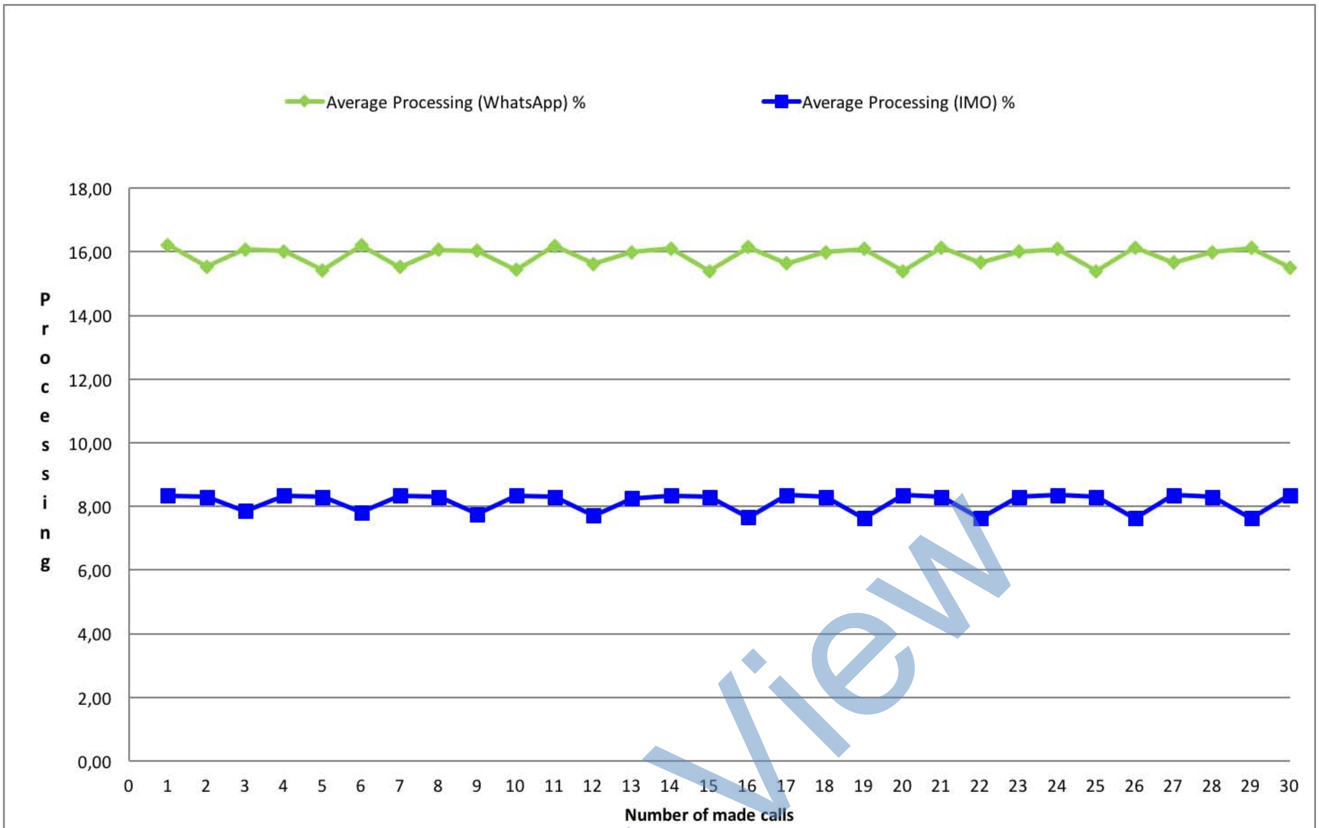
Figure 1 : Data Collection Interface in Little Eye (Source: Little Eye)

interest, as illustrated in the following screen (Fig. 1).

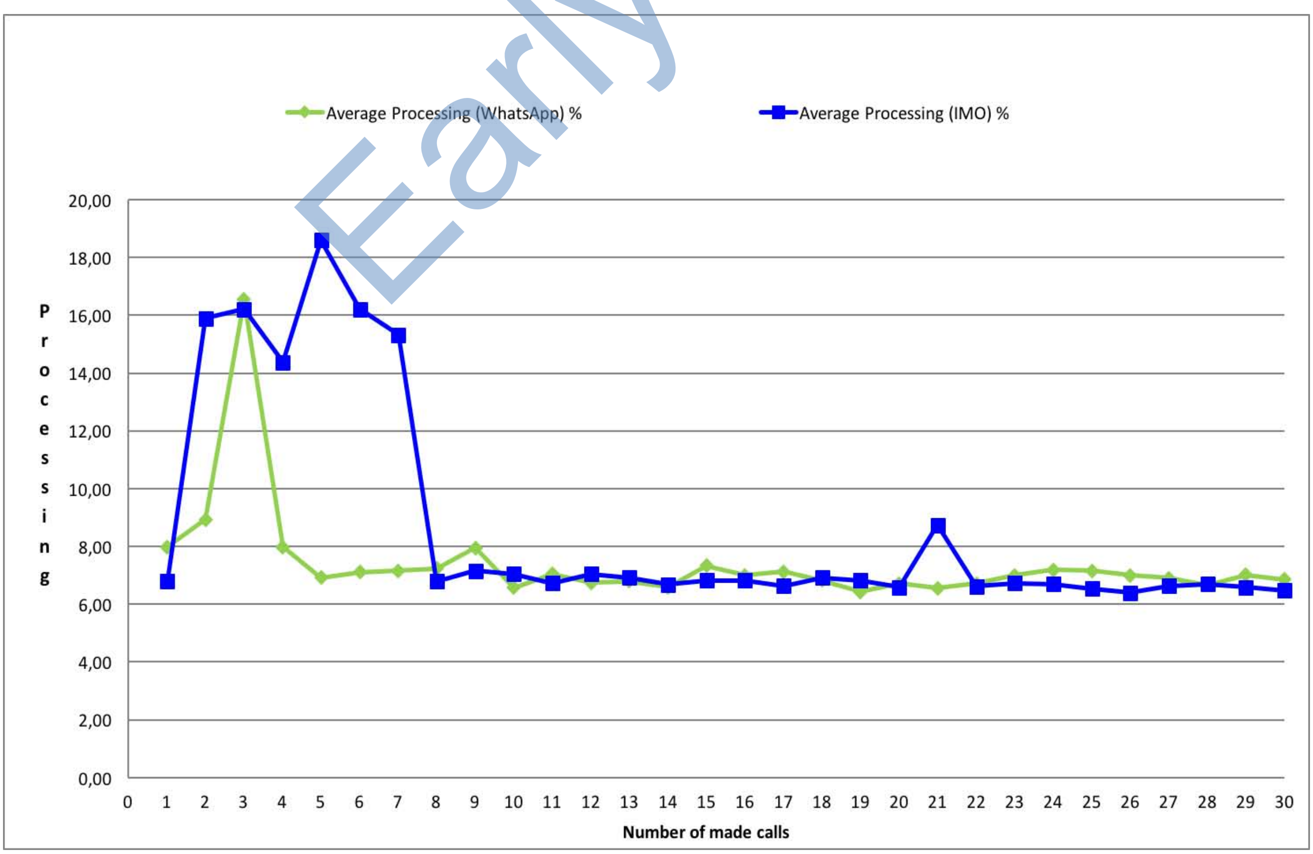
Case Study: The application under test is monitored with VoIP call duration of 1 minute, 5 minutes and 10 minutes. The data were collected during these periods. In a preliminary analysis, 30 calls with WhatsApp and IMO were refereed. The same test environment is applied to both Android KitKat (KK) and Lollipop (LL) systems, i.e., the same test conditions and analysis are adhered so there is no bias in results. Standard hypothesis tests were conducted to ascertain a performance difference between IMO and WhatsApp applications. Two-tailed t-test for the population mean of IMO under a cornucopia of scenarios. Let _ be the mean of CPU requirements of the application during a 10 minutes VoIP call (sending or receiving). The statistical hypothesis at 1% significance level (_ = 0:01) were:

$$\begin{aligned} null-hypothesis \quad & H_0 : \mu_{IMO} = \mu_{Whatsapp} \\ alternative-hypothesis \quad & H_1 : \mu_{IMO} \neq \mu_{Whatsapp}. \end{aligned} \quad (1)$$

Also, left-tailed t-test showed evidence that IMO performance was higher than WhatsApp. Bean plot is also used to visualize performance data http://boxplot.Tyerslab.com/.



(a) smartphone (Galaxy Note 4), OS (KitKat), transsmission medium (3G)



(b) smartphone (Galaxy),OS (Lollipop), transmission medium (Wifi)

Figure 2 : VoIP connection 10 minutes (WhatsApp / IMO), with smartphone receiving messages

III. Performance of Whatsapp and Imo

Data collection was conducted using the Little Eye software as application performance analysis tool [7]. In this software, it is possible to collect smartphone application logs and analyze the processing consumption. This tool has a number of resources available to perform the analysis of applications, ranging from battery consumption to processingoverhead. In these experiments, however, the scope has been narrowed to the study of behavior around the CPU. The test was carried out by collecting 30 calls lasting 10 minutes and the logs generated took the average for all sampling measures. These graphs show the applications are processed for use in receiving (also transmitting) a VoIP call through WhatsApp and the IMO using a WiFi connection as communication in both versions of Android [15]. Figure 2, illustrates two instances of selected CPU requirements measures for achieving 30 calls, lasting 10 minutes. Each point is the average calculated from 30 samples. All correlations between performances in different scenarios were calculated: Higher performance correlations were obtained for the handset Galaxy S4 than for the Galaxy Note 4. The highest correlation coefficient among all tested scenarios was obtained for the Galaxy S4 with WhatsApp for transmitting/receiving text messages. Even requiring a memory load of roughly twice, the wifi operation under the android LL had a similar behavior to a 3G transmission with the android version KK. For WhatsApp using the KitKat OS, the smartphone Galaxy S4 presented some correlation between 3G and wifi. The KK android version yielded performance results not so sensitive to the selected network (3G or wifi operation) and their memory requirements were pretty close. Still handling with WhatsApp on the device S4 operating on wifi, there is a performance correlation between the two android OS version, but the KK performance is roughly twice more efficient than the operation with LL. Considering now the IMO application, in the 3G operation under Galaxy S4 smartphone, the general performance behavior is weakly sensitive to the selected version of the android system. Nevertheless, the performance of KK OS was approximately twofold more efficient than LL, as concerning 3G transmission. In contrast, the lowest correlation coefficient was found for KitKat in the two handset models, where the WhatsApp and IMO application performance for 3G calling were noncorrelated. Low correlations were also achieved for 3G connections on the smartphone Galaxy Note 4: the performance for KitKat and Lollipop were also uncorrelated.

Table 1 : Average CPU requirements for different scenarios. Smartphone Galaxy Models: N4 and S4. The calls were all made lasting 10 minutes. In each case, they were considered N = 30 samples (each is an average obtained from 600 measurements). Values in parenthesis refer to the sample. standard deviation. Significance level of t-test: _ = 0:01

	3G	KitKat	3G	Lollipop	WiFi	KitKat	WiFi	Lollipop
handset	WApp	IMO	WApp	IMO	WApp	IMO	WApp	IMO
Galaxy N4	15.97^a	7.66^b	15.64^a	6.51^b	7.40^a	8.68^a	16.18^a	8.42^b
	(0.48)	(0.56)	(0.10)	(0.29)	(1.80)	(3.84)	(1.00)	(0.44)
Galaxy S4	10.15^a	20.67^b	23.69^a	34.25^b	11.87^a	19.90^b	18.74^a	46.78^b
	(1.64)	(0.52)	(0.68)	(3.07)	(1.11)	(0.57)	(7.80)	(1.19)

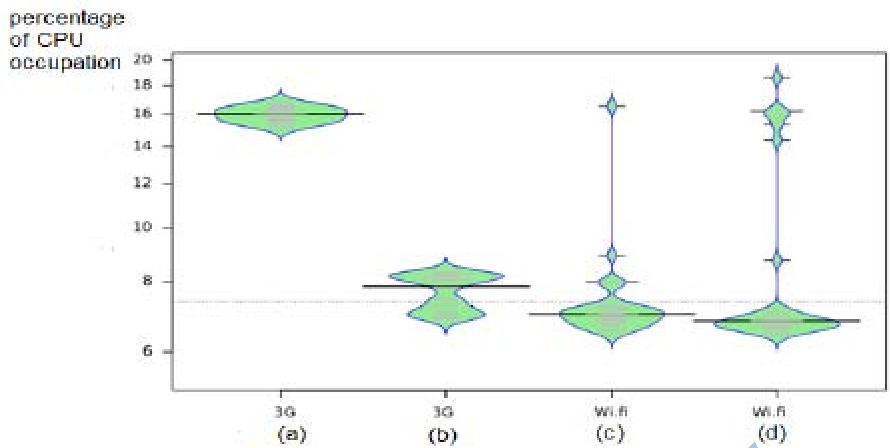


Figure 3 : Beanplot of CPU requirements for the following scenario: Android OS KitKat, mobile device Samsung Galaxy Note 4 and transmitting calls mode. For 3G operating mode: a) Whatsapp and b) Imo. For WiFi operating mode: c) Whatsapp and d) IMO

It was observed that a few specific moment, the processing occupation reached to zero. Sometimes this is expressed by display off (device screen hibernated,) it reduced the kernel processing consumption. It was noticed that the tester there are three or more CPUs and the WhatsApp test has shown the using of a single CPU. But this led to the idea that some features of the devices were being processed by other CPUs. In some cases it was perceived that the application falls under Lollipop, but it is emphasized that troubles may have occurred during the collection of logs. An example is the Internet itself both 3G as WiFi, tool communication with the device or operating failures. In the beanplot (a variant of Tukey boxplot) shown in Fig. 3, one can see the behavior of CPU requirements for measurements comparing the transmission medium (3G _ WiFi) for WhatsApp and IMO. For 3G, a marked performance difference is observed between Whatsapp and IMO in the Samsung Note 4, showing a superior performance of IMO. In contrast, underWiFi, these differences are not so remarkable. Table 1 (tx) and 2 (rx) present the statistics of average CPU requirements obtained in the pairwise measurements in order to compare the performance of WhatsApp and IMO. A marking with different letters (e.g. a and b) indicates that the average CPU requirements were different at a significance level of 1% (so the hypothesis H0 can be rejected). A pairwise comparison with the same letter (a and a) indicates that the null hypothesis cannot be discarded at 1%, i.e. there is no statistical evidence of performance difference between the two scenarios compared. In the first table, only the operating system version is changed (KitKat _ Lollipop). In the second one, it is varied just the transmission medium (3G _ WiFi). Null hypothesis (Eqn. (1)) is rejected at 1% significance level in all cases, but fKK,N4,wifig where the performance of the IMO and WhatsApp is statistically indistinguishable (t=1.826, p-value=0.078). p-values were p < 10□5 in most cases. Also, left-tailed test have shown evidence to accept the hypothesis _IMO < _WhatsApp (or _WhatsApp < _IMO). t-tests on Galaxy Note 4 have shown that IMO app has a statistical better performance that WhatsApp whatever the Android, at a significance level 1%.In contrast, WhatsApp requires less CPU than IMO on Galaxy S4 at the same significance level, whatever the OS and the access network (3G/Wifi). Finally, Galaxy Note 4 using WiFi outperforms Galaxy S4 in terms of processing.

Table 2 : Average CPU requirements for different scenarios. Smartphone Galaxy Models: N4 and S4. Receiving message calls lasting 10 minutes. In each case, they were considered N = 30 samples (each is an average obtained from 600 measurements). Values in parenthesis refer to the sample standard deviation. Significance level of t-test: _ = 0:01

	3G	KitKat	3G	Lollipop	WiFi	KitKat	WiFi	Lollipop
handset	WApp	IMO	WApp	IMO	WApp	IMO	WApp	IMO
Galaxy N4	15.81^a	8.15^b	15.86^a	8.13^b	7.22^a	6.43^a	15.37^a	8.33^b
	(1.20)	(2.00)	(0.10)	(0.29)	(0.47)	(0.19)	(1.04)	(0.55)
Galaxy S4	11.57^a	19.75^b	23.41^a	34.92^b	10.61^a	19.89^b	22.60^a	39.40^b
	(1.50)	(0.25)	(0.49)	(2.68)	(1.20)	(0.30)	(0.77)	(5.90)

IV. Conclusions

There is visible the increased processing generated by the application in the version of Lollipop compared the KitKat version. However, both on WiFi and 3G connections, there is insufficient data here to unveil the very reason, but we know that changes made to the KitKat to Lollipop are focused on managing resources, such as energy consumption [13]. Based on the results we can say that the operating system indirectly affects in the response in terms of CPU processing, although it may not be decisive. When comparing the same operating system on different chipsets we realize that the application the way it was developed directly contributes to the device performance. This claim comes from the realization that IMO on Galaxy S4 requires more CPU than WhatsApp, but on the other hand, this does not occur in the Galaxy Note 4. It is also observed that WiFi under Galaxy Note 4 has better performance than the Galaxy S4 in terms of processing, for both operating systems. This is quite likely to happen due to the CPU management, since each chip has its own managing way. In the 3G scenario, more CPU is required in both IMO and WhatsApp. It is assumed that the chipset combination, application development, Android OS and the network technology (WiFi/3G) is crucial in CPU performance. The total processing using this application be given by the sum of CPU usage by the user (application) and CPU usage by the kernel generated by the application itself. Nevertheless, findings suggest the need for a more specific analysis from the perspective of resources exploited by each application. Ascertain the impact of energy consumption with the device update to the Android Lollipop version should also be examined, since it is one of the notes issued for this release. It is so recommended as future research a deep investigation on energy consumption [11], [6] achieved with the device to update the version Lollipop. (http://cs.gmu.edu/˜astavrou/research/ Android_Power_Measurements_Analysis_SERE_12.pdf). Applications should have the chipset/OS as a key observance with a view on battery consumption.

V. Acknowledgment

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Pervasive Computing Applications using Different Computational Platforms

By Nicy Kaur Taneja & Dr. S.R.N. Reddy

Indira Gandhi Delhi Technical University for Women

Abstract- This paper provides an insight into the concept of computing and their applications. Different computational boards are available in the market for the development of a smart device. Many applications can be developed for the ease of the society. These devices provide great computing functions with mobility too and are smart enough to sense the surroundings. The paper will enlighten some of the important features of the computational platforms and three different applications using them depending on their functionalities.

Keywords: pervasive computing, raspberry PI, intel galileo gen2, ARM MBed.

GJCST-A Classification : C.2.1, I.3.5

PERVASIVECOMPUTINGAPPLICATIONSUSINGDIFFERENTCOMPUTATIONALPLATFORMS

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Keywords: pervasive computing, raspberry PI, intel galileo gen2, ARM MBed.

I. Introduction

The concept of computingenlightens the utilization of computer technology by involving hardware and/or software. Most of us use the computing technology in our day-to-day life but we may or may not realize it. The swiping of our credit/debit cards, smart phones, metro smart cards etc. utilizes the computing technology. The data was easily shared by distributing them acrosss different computers located at different locations. But due to its shortcomings of variation in network quality, limitation of weight and size of systems and constraint of battery consumption. These constraints led to the research of mobile computing in which each of the three: communication, hardware and software are mobile [4]. It involves mobile networking, mobile information access, location sensitivity and energy saving techniques due to size of devices compared to large computer systems. The mobile device has some characteristics that produces the output depending on its location. For example, if a person sets the ringing of his mobile phone as vibration while in conference and on ringing while travelling then the application will utilize the user's location.

The context-awareness is a part of location sensitivity [1]. It is not only limited to location. In fact it covers time, identity, light and social factors too. The mobile device presents the output depending on its inference from the surrounding characteristics and guides through the information surrounding us.

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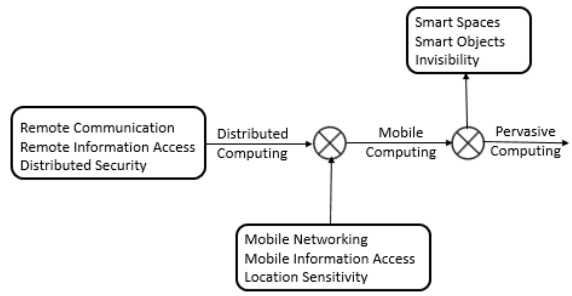

Figure 1 : Trends in Computing

Later on, to make these devices smart, the research led to pervasive computing. Pervasive computing provides an environment in which people interact with embedded processors or computers in a smart way [5].

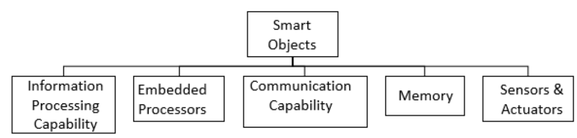

Figure 2 : Hardware and Software Components of Smart Objects

Some of the development boards are used for developing mobile applications whereas some for pervasive applications. The smart objects of pervasive computing application has information processing capability, embedded processor, communication capability, memory and the sensors and actuators.

II. Literature Survey

Komal Tayde and Prof. Amit Bhala [4] described the principles of context awareness, its applications and usability. They also addressed the risks involved in building context aware applications and the solutions to deal with them. Charith Perera, Chi Herold and Min Chen [1] surveyed number of IoT solutions in terms of context-aware technology perspectives. Renuka and Prof. Vijay Bagdi [3] implemented a surveillance system using Raspberry Pi and PIR sensor to send the captured images to user's email id. Deepali and Mukund [5] gave an insight into the concept of context, its need, design principles, models and requirement of context awareness applications. The context models describes how the context data is stored such as simple data structure, hierarchical data structure, graphical structure or using object-oriented techniques.

III. Computational Platforms

a) Raspberry Pi Development Board

Raspberry Pi is a small computing platform which is not limited to run only on Linux but on Android and Windows operating system too [11]. It provides the hardware ports to connect USB, keyboard, mouse, microphone, speaker, camera, HDMI cable and SD card slot. This hardware platform can be prototyped to design a complete stand-alone computing system. It is best suited for application that requires multimedia support such as camera, audio and video. If the Linux image is used, the programming can be done in Python. If Raspberry Pi uses Windows platform, then the programming can be done using Microsoft Visual Studio IDE.

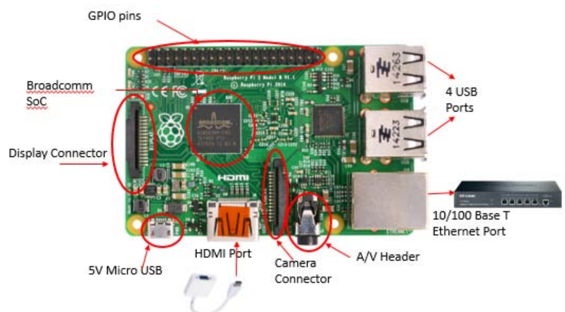

Figure 3 : Raspberry Pi2 Development Board [7]

b) Intel Galileo Gen2 Development Board

A development platform provided by Intel with on-board analog to digital converter. Both analog and digital components can be connected to the board. The supported programming environment is Arduino IDE and Eclipse. It has an Intel Quark SoC x1000 processor [10]. The board can be powered up by using a 12V power adapter. The program running on the board is saved in a flash memory and the memory gets removed after the power is removed. So, I order to save the program, SD card can be used. The board can be connected to the internet through Ethernet.

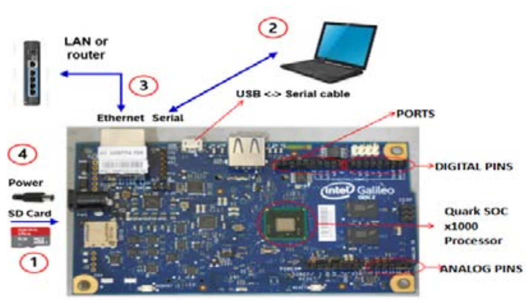

Figure 4 : Intel Galileo Gen2 Development Board [8]

c) ARM MBed Development Board

The Mbed has an ARM microcontroller in which is designed for prototyping low cost USB devices, battery powered applications [6]. It is packaged as a small DIP form-factor for prototyping with through-hole PCBs, strip board and breadboard, and includes a built-in USB FLASH programmer. The board has an interface for both analog and digital sensors. For interfacing communication modules, transmitter and receiver pins are also available. It has a reset button which is used to erase any saved program in the board's memory. It also has four on-board LEDs. It can be programmed using a lightweight online compiler.

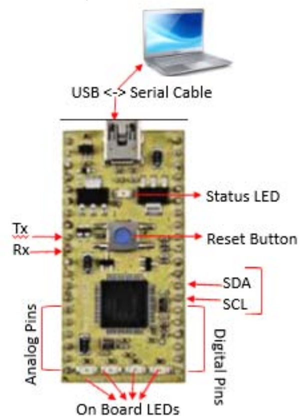

Figure 5 : ARM MBed Development Board [7]

d) Comparison among Different Computational Platforms

The table gives an insight into the difference of hardware features between three different platforms. These differences helped us to effectively select the development board for its application. All the computational platforms has different operating frequencies. Their hardware and software features make them suitable for different applications. Raspberry Pi 2 can be used to design a complete mobile device but its distinctive feature is that it supports video and camera functionality. It has USB ports for connecting mouse, keyboard or other peripheral devices. Whereas Intel Galileo Gen2 can be used to design pervasive devices that are smart enough to sense the environment. ARM MBed board can be used to design smart devices that require less space.

Table 1 : Comparison of Different Computational Platforms

S.No.	Parameter	Raspberry Pi 2	Intel Galileo Gen2	ARM MBed
1.	SoC / Microcontroller	Quad core Broadcom BCM2835	Intel Quark X1000 SoC	ARM Cortex-M0
2.	Max. Operating Frequency (MHz)	900	400	48
3.	Power pins	Either 3.3 or 5V	Either 3.3 or 5V	4.5 to 9V
4.	Application	Suitable for handling media such as photos or video	Suitable for project involving sensors &their monitoring	Suitable for low cost USB devices & battery powered applications
5.	Booting	Boots only from SD card	Can boot from on-board memory + SD Card Support	Can boot from on-board memory
6.	On-board ADC	No	Yes	Yes
7.	Ethernet & USB support	Yes	Yes	USB only
8.	Power Supply	5V	5V for Gen1 but on-board regulator on Gen2 7V - 15V	5V USB

IV. Experiments

After studying the hardware and software features of all the three development boards, different sensors were interfaced with them. This was done to build different pervasive applications on different platforms.

a) To monitor room temperature using ARM Mbed Development Board

To monitor the room temperature, LM35 temperature sensor was interfaced with the computational platforms.

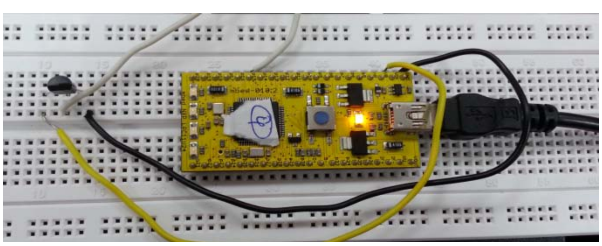

Figure 6 : LM35 interfaced with ARM Mbed

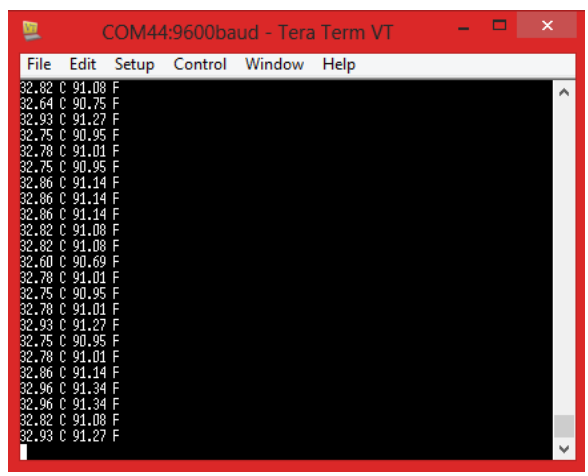

Figure 7 : Temperature Display on Serial Monitor

b) To capture image using Raspberry Pi Development Board

For capturing an image, camera was connected to CSI port on Raspberry Pi board. To start the camera, first it has to be enabled and then a python command to capture the still image. The image will be saved with ".jpg" format. Similarly, video can be recorded using the same camera and it will be saved with a ".h264" format.

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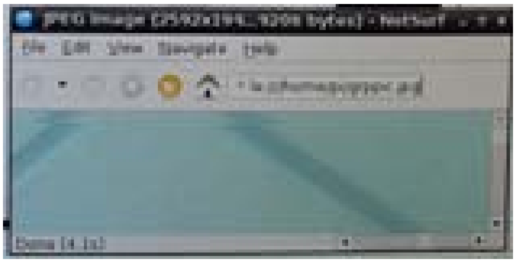

Figure 8 : Captured Image

c) *To detect the motion of a person using Intel Galileo Gen2 Development Board*

The Passive Infrared (PIR) gives the output by measuring the Infrared light emitted by an object in its field. PIR sensor and buzzer were used to detect if any person passes in front of the sensor. When an object having temperature above absolute zero and emits heat energy in the form of radiation, it is detected by the motion sensor. As soon as the motion is detected, the buzzer starts ringing.

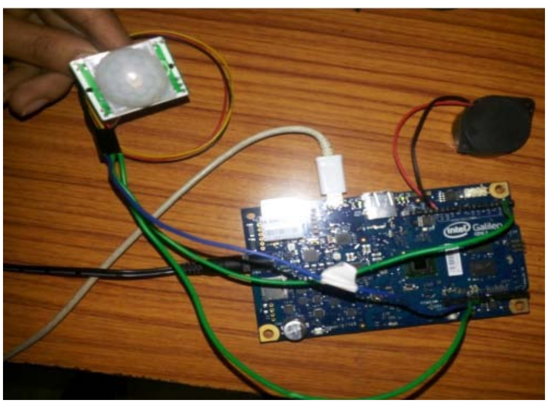

Figure 9 : PIR sensor and Buzzer interfaced with Intel Galileo Gen2

V. Conclusion

The trend of computing helped to understand the present computing scenario in terms of its need, structure and applications to the user as well as the society. The differences among the different computational platforms provides an intellectual understanding of their features. The selection of platform was done successfully to develop different applications based on their functionalities.

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Multiuser Parallel Transmission with 1-Tap Time Domain Beamforming by Millimeter Wave Massive Antenna Arrays

By Kazuki Maruta, Atsushi Ohta, Takuto Arai, Tatsuhiko Iwakuni, Yushi Shirato, Satoshi Kurosaki & Masataka Iizuka

Nippon Telegraph and Telephone Corporation

Abstract- This paper investigates the feasibility of multiuser parallel transmission by sub-array beamforming using millimeter wave bands in which the Line-of-Sight (LoS) dominant channel environment is expected. Focusing on high beamforming gain provided by the massive antenna array, each sub-array conducts first eigenmode transmission and thus one stream is allocated per user without null steering. This paper also proposes 1-tap time domain beamforming (TDBF) as the same weight is applied to all frequency components.

Keywords: massive antennas, sub-array, first eigenmode, time domain beamforming, parallel transmission. Milli meter wave.

GJCST-A Classification : D.4.4, C.1.4

MULTIUSERPARALLELTRANSMISSIONWITH1-TAPTIMDOMAINBEAMFORMINGBYMILLIMETERWAVEMASSIVEANTENNAARRAYS

Strictly as per the compliance and regulations of:

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Kazuki Maruta α, Atsushi Ohta σ, Takuto Arai ρ, Tatsuhiko Iwakuni Ѡ, Yushi Shirato ¥, Satoshi Kurosaki§ & Masataka Iizuka χ

Abstract- This paper investigates the feasibility of multiuser parallel transmission by sub-array beamforming using millimeter wave bands in which the Line-of-Sight (LoS) dominant channel environment is expected. Focusing on high beamforming gain provided by the massive antenna array, each sub-array conducts first eigenmode transmission and thus one stream is allocated per user without null steering. This paper also proposes 1-tap time domain beamforming (TDBF) as the same weight is applied to all frequency components. It reduces computation complexity as well as suppressing the effect of additive noise on weight derivation. Computer simulation results show that increasing the sub-array spacing stably improves signal-to-interference power ratio (SIR) performance and that the proposed 1-tap TDBF can match the performance of the frequency domain first eigenmode transmission as a rigorous solution.

Keywords: massive antennas, sub-array, first eigenmode, time domain beamforming, parallel transmission. Milli meter wave.

I. Introduction

The rapid spread of wireless communication devices such as smartphones and tablets has triggered diversification in mobile services. Not only is data traffic exploding, but also large numbers of terminals are crowding key sites such as station, airports and event venues. Unfortunately, frequency resources are being depleted rapidly, especially in the microwave band since many kinds of wireless communication systems such as wireless fidelity (Wi-Fi), worldwide interoperability for microwave access (WiMAX) or long-term evolution (LTE) (-Advanced) have become voracious consumers. Overcoming this shortfall is a critical issue in wireless communication. Drastic improvements in transmission rate and system capacity are required towards 5th generation mobile communications (5G) [1]. Promising solutions [2, 3] include micro-cells for area spectral efficiency improvement and exploiting millimeter wavebands such as super high frequency (SHF) or extremely high frequency (EHF) bands where rich spectrum resources are available. The main problem in using millimeter wavebands is the link budget shortfall. The propagation loss is high and the performance of radio frequency (RF) components such as high power amplifier (HPA) is limited in millimeter wavebands.

The application of massive multiple-input multiple-output (MIMO) [4-7] is one of the most promising solutions. Massive MIMO can provide large beamforming gain with huge numbers of arrayed antenna elements without high-performance high-cost RF components [8]. In addition, higher order space division multiplexing (SDM) can be applied by using its excess degree of freedom (DoF) to enhance the transmission rate. It is noted that higher order SDM divides total transmission power but the beamforming gain should be sufficient to perform SDM. The beamforming gain is, ideally, given by $10\log_{10}(NtNr)$ dB, where Nt and Nr are the numbers of transmission and reception antenna elements, respectively. This means that increasing the number of antenna elements from 100 to 200 yields a gain of only 3 dB making arrays with more than 100 elements not cost effective. If the link budget is insufficient with the use of around 100 elements, we have only two options; one is limiting the service area to reduce the propagation loss and the other is employing directional antennas to attain larger antenna gain. A high-functionality base station (BS) with massive array is expensive making quite small service areas unacceptable from the operating viewpoint. On the other hand, the use of directional antennas raises the correlation of the antenna elements of user equipment (UE). This results in a large level gap between the 1st and 2nd eigenvalues which hinders higher order SDM application [9]. Moreover, the feasibility of higher order SDM in actual environments has not been confirmed for future BSs and UEs with practical specifications. From the above background, this paper discusses a different approach to exploiting massive element numbers with Line-of-Sight (LoS) dominant channels.

The next promising approach to obtain higher system capacity, multiuser MIMO [10], spatially multiplexes the UEs to use the same frequency channel at the same time. As described above, channel environments in millimeter wavebands are considered to be dominated by the LoS component since BS and/or

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UEs are required to have highly directive antennas in order to obtain adequate transmission/reception performance. In such situation, multiuser diversity gain is expected to increase the system capacity [9, 11] since the inter-user correlation between UEs is lower than intra-user correlation. In other words, it can be a promising solution for the problem of the large level gap between the 1st and 2nd eigenvalues in the LoS dominant channel for a single user MIMO. Meanwhile, to spatially multiplex several UEs, the BS requires channel state information at the transmitter (CSIT) to suppress inter-user interference (IUI). The accuracy of CSIT is degraded by the channel time variation created by movement of the UEs or objects around the UEs. Inaccurate CSIT causes incomplete IUI suppression which degrades the signal-to-interference power ratio (SIR) performance of multiuser MIMO [12]. We have verified one of the massive MIMO benefits; the improved robustness of multiuser transmission in time varying channel environments [13]. The gain of the beamforming provided by a massive array is concentrated on the target UE and the average level of IUI leakage in the space is adequately suppressed. This causes high energy efficiency and minimal IUI leakage between the multiplexed UEs even with user movement. From the above features, we are focusing on multiuser massive MIMO which allocates only 1st eigenmode to each UE to achieve stable and enhanced system capacity even in high mobility situations [9]. Given the LoS environment, 1st eigenvalue usage is outstandingly effective since its transmission/reception beams are much more stable than those for 2nd and higher order eigenmodes. However, block diagonalization (BD) or singular value decomposition (SVD) computations of large-scale matrices for each frequency component incur quite heavy computation loads given the assumption of millimeter wideband transmission. The effective solution of hybrid analog/digital beamforming has been studied [8, 14-17]. Analog beamforming can reduce costly RF chains and the computation costs associated with digital processing. It requires beam training or search with the use of pre-determined beam patterns, which imposes some overhead. In the 5G world, it is expected that the number of accommodated UEs in a cell will become larger and it may makes the overhead heavy. These are the reasons why a breakthrough in simplified massive MIMO operation is required.

This paper first investigates the feasibility of multiuser parallel transmission via isolated sub-arrays (SAs). BS uses multiple SAs that are separated from each other and only 1 signal stream per SA is allocated to each UE via 1st eigenmode without null steering. This elimination of signal processing for null steering eases the total computation load. The isolation of all transmission and reception points from each other helps to ensure low correlated channels so null steering is not necessary. Second, we introduce 1-tap time domain beamforming (TDBF) to drastically alleviate this calculation cost. TDBF weight can be determined by simply correlating reception signals between antenna elements, which basically corresponds to extracting the strongest path, i.e., the LoS component. When SA is a narrow-spaced array (e.g. half-wavelength), incoming direct wave signals are regarded as plane waves. In this case, the frequency dependence of the weight is limited and it is possible to employ constant weights in the frequency domain. As a result, the 1-tap TDBF weight can be applied to all frequency components. Furthermore, it can be obtained under very low SNR conditions, less than 0 dB, without beamforming. Assuming that we assign a single stream to each SA and UE, the signal processing for TDBF can be significantly simplified even though full digital signal processing is employed and hardware resource requirements can be minimized with optimized designs. The contributions of this paper are: 1) The SIR performance of SA beamforming is revealed for the parameters of SA spacing, SA antenna element number, Rician *K*-factor, and UE movement speed. 2) A 1-tap TDBF scheme is presented and its effectiveness is verified.

The rest of this paper is organized as follows. Section 2 defines the system model and presents the methodology of multiuser parallel transmission by the sub-arrayed BS configuration. Section 3 describes the 1-tap TDBF scheme. Computer simulation results are provided in Section 4. Finally, Section 5 concludes the paper. Throughout the paper, normal letters represent scalar quantities, bold lowercase letters indicate vectors and uppercase letters indicate matrices. $|.|$, $(.)^*$, $(.)^T$, and $(.)^H$ represent absolute values, conjugate values, transpose and conjugate transpose, respectively.

II. System Definition

a) System and Channel Model

The system model is depicted in Fig. 1. BS is composed of *Na* SAs, each of which has *Nt* elements in a uniform planar array (UPA). SA serves one UE with *Nr*

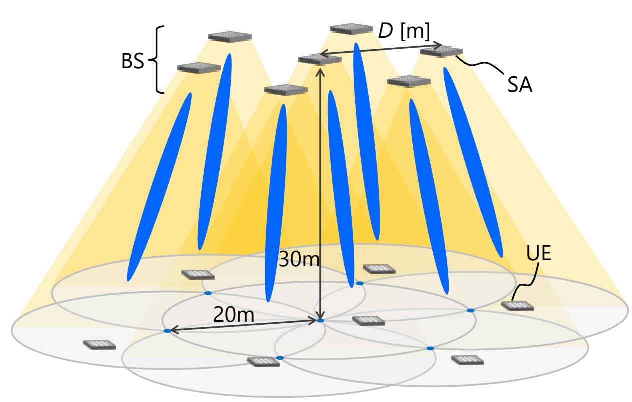


Figure 1 : System model

UPA elements via beamforming; only a single stream is allocated to each UE. To ensure the LoS environment and reduce the probability of human blockage [18], SAs should be installed at high positions. To provide a simple evaluation of the potential of the proposed method, BS is assumed to be ceiling mounted and UEs face straight up as shown in Fig. 1. This scenario can be realized at stadiums and large halls like exhibition centers, and simple variants will support different situations such as installation of the walls of buildings. Fig. 1 shows a typical case for a simple feasibility study. Assuming multicarrier transmission such as orthogonal frequency division multiplexing (OFDM), we define the channel matrix per subcarrier, $\mathbf{H}\in\mathbb{C}^{NuNr\times NaNt}$, as follows;

$$\mathbf{H} = \left[\mathbf{H}_1^T \quad \cdots \quad \mathbf{H}_i^T \quad \cdots \quad \mathbf{H}_{Nu}^T\right]^T \tag{1}$$

$$\mathbf{H}_i = \left[\mathbf{H}_{i1} \quad \cdots \quad \mathbf{H}_{ij} \quad \cdots \quad \mathbf{H}_{iNa}\right] \tag{2}$$

where $\mathbf{H}_i\in\mathbb{C}^{Nr\times NaNt}$ denotes the channel sub matrix between the i-th UE and BS. Note that these expressions are per subcarrier and indices have been omitted. A Rician fading channel is considered so $\mathbf{H}_i$ is expressed using Rician K-factor as,

$$\mathbf{H}_i = \sqrt{\frac{K}{K+1}}\,\mathbf{H}_{LoS,i} + \sqrt{\frac{1}{K+1}}\,\mathbf{H}_{NLoS,i} \tag{3}$$

$\mathbf{H}_{LoS,i}$ is determined by the spatial relationship of the i-th UE and BS;

$$\mathbf{H}_{LoS,i} = \frac{\lambda}{4\pi}\begin{bmatrix} \dfrac{e^{-j2\pi\frac{d_{11}}{\lambda}}}{d_{11}} & \cdots & & \dfrac{e^{-j2\pi\frac{d_{1(NaNt)}}{\lambda}}}{d_{1(NaNt)}} \\ & \ddots & & \\ \vdots & & \dfrac{e^{-j2\pi\frac{d_{mn}}{\lambda}}}{d_{mn}} & \vdots \\ & & \ddots & \\ \dfrac{e^{-j2\pi\frac{d_{Nr1}}{\lambda}}}{d_{Nr1}} & \cdots & & \dfrac{e^{-j2\pi\frac{d_{Nr(NaNt)}}{\lambda}}}{d_{Nr(NaNt)}} \end{bmatrix} \tag{4}$$

where d_{mn} is the distance between the m-th antenna element of i-th UE and the n-th BS antenna element. λ is the carrier wavelength. The channel time variation of $\mathbf{H}_{LoS,i}$ is simulated by the spatial relationships between the UEs and the BSs as determined by UE movement. $\mathbf{H}_{NLoS,i}$ is the non-line-of-sight (NLoS) component from the scatters, which are uniformly sited around the UEs. Each element of $\mathbf{H}_{NLoS,i}$ also includes a path loss coefficient of $\lambda/(4\pi d_{mn})$. To consider the spatial correlation between BS antenna elements, independent identically distributed (i.i.d.) Rayleigh fading channels are converted into correlated channels using the Kronecker model [19]

$$\mathbf{H}_{NLoS,i} = \mathbf{R}_{rx,i}^{1/2}\,\mathbf{H}_{iid,i}\,(\mathbf{R}_{tx,i}^{1/2})^T \tag{5}$$

where $\mathbf{R}_{tx,i}\in\mathbb{C}^{Nt\times Nt}$, $\mathbf{R}_{rx,i}\in\mathbb{C}^{Nr\times Nr}$ are correlation matrices [20]. Assuming the 3GPP 3D channel model [21], the half power beamwidth (HPBW) of each antenna element is set to 65°. The power azimuth spectrum (PAS) of an arriving path at the base station is assumed to have a Laplacian distribution [22] and its deviation value is set to 5°. Time variation of the NLoS component follows Jakes' model [23].

b) Sub-Array Multiuser Parallel Transmission by First Eigenmode

The i-th UE obtains a sub-block channel matrix to the i-th SA, $\mathbf{H}_{ii}\in\mathbb{C}^{Nr\times Nt}$, and computes the SVD [10].

$$\mathbf{H}_{ii} = [\mathbf{u}_i \quad \overline{\mathbf{U}}_i\,]\,\mathbf{\Sigma}_i\,[\mathbf{v}_i^H \quad \overline{\mathbf{V}}_i^H\,] \tag{6}$$

where $\mathbf{u}_i\in\mathbb{C}^{Nr\times 1}$ and $\mathbf{v}_i\in\mathbb{C}^{Nt\times 1}$ represent left and right singular vectors corresponding to the 1st eigenmode, respectively. $\mathbf{\Sigma}_i\in\mathbb{C}^{Nr\times Ns}$ is a singular value matrix whose diagonal elements are arranged in descending order. With the LoS dominant channel, it is expected that the 1st eigenmode weight vectors $\mathbf{u}_j^H$ and $\mathbf{v}_i$ attain beamforming gain by extraction of the LoS component. Denoting the transmission signal vector of all UE/SAs as $\mathbf{T} = [t_1, \ldots, t_i, \ldots, t_{Nu}]^T\in\mathbb{C}^{Nu\times 1}$, reception signal vector, $\mathbf{Y} = [y_1, \ldots, y_i, \ldots, y_{Nu}]^T\in\mathbb{C}^{Nu\times 1}$, is expressed as follows;

$$\mathbf{Y} = \begin{bmatrix} \mathbf{u}_1^H & & \mathrm{O} \\ & \ddots & \\ \mathrm{O} & & \mathbf{u}_{Na}^H \end{bmatrix} \mathbf{H} \begin{bmatrix} \mathbf{v}_1 & & \mathrm{O} \\ & \ddots & \\ \mathrm{O} & & \mathbf{v}_{Na} \end{bmatrix} \mathbf{T} + \mathbf{n} \tag{7}$$

where $\mathbf{n}$ is an additive white Gaussian noise (AWGN) vector. It should be noted that $Na = Nu$. The i-th UE and SA perform beamforming only to each other as an isolated system and do not care about the other j-th ($i\neq j$) UE/SA pairs. If SAs are spatially de-correlated with large enough inter-SA spacing, significant SIR gain can be expected without null steering. SIR and SINR for the i-th UE are given by;

$$\mathrm{SIR}_i = 10\log_{10}\frac{\left|\mathbf{u}_i^H\mathbf{H}_{ii}\mathbf{v}_i\right|^2}{\sum_{j=1,j\neq i}^{Na}\left|\mathbf{u}_i^H\mathbf{H}_{ij}\mathbf{v}_j\right|^2} \tag{8}$$

$$\mathrm{SINR}_i = 10\log_{10}\frac{\left|\mathbf{u}_i^H\mathbf{H}_{ii}\mathbf{v}_i\right|^2}{\sum_{j=1,j\neq i}^{Na}\left|\mathbf{u}_i^H\mathbf{H}_{ij}\mathbf{v}_j\right|^2+\sigma^2} \tag{9}$$

where σ^2 is the noise variance defined as single-input single-output (SISO) situation.

III. 1-Tap Time Domain Beamforming

First of all, we have set up a hypothesis for the LoS dominant channel such that the first eigenmode reception weight can be approximately obtained as the simple reception weight determined for the case in which only a single antenna element located around the center of the array antenna at UE side transmits a training signal for channel estimation. Though it is done in a quite low SNR condition because of the link budget shortfall, the subsequent application of TDBF makes accurate weight estimation under such condition possible. After obtaining an adequate transmission weight at BS side, UE can easily obtain the MRC reception weight by receiving training signal transmitted from SA at BS side with the transmission weight. In millimeter wave communication, inter-element spacing becomes much smaller than BS-UE distance. In the case of Fig. 1, BS uses a directional antenna to improve the link budget, so angle-of-departure (AoD) and/or angle-of-arrival (AoA) at BS side is quite small. In this case, when we observe relative phase information to the reference antenna element, in-band phase fluctuation is not so huge whereas the individual phase information fluctuates largely with bandwidth. The individual phase information is given by $2\pi d_m f/c$ where d_m is the distance between transmission/reception antennas, f is the carrier frequency and c is the light speed. Meanwhile, the relative phase information of the m-th antenna element is given by $2\pi\Delta d_m f/c$ where Δd_m is the path length difference between the m-th antenna element and the reference antenna element (e.g. the 0-th element), i.e. $\Delta d_m = d_m - d_0$. Here, $d_m >> \Delta d_m$ and $2\pi\Delta d_m f/c$ is negligible [9]. Note that the beamforming weight is determined by the relative CSI instead of absolute CSI; common phase offset for all elements is not important. The stable relative phase information enables us to apply the same beamforming weight for all frequency components. Fourier transformation of the constant weight in the frequency domain yields an impulse shaped tap coefficient in the time domain, i.e. a 1-tap TDBF weight. Though clearly a simplified scheme, it can still strengthen the dominant arriving path.

Fig. 2 overviews the proposed 1-tap TDBF. First, a training signal is transmitted from one UE antenna element at the UPA's center. Received signal for the m-th antenna element (m = 0, 1, ... , Nt-1) of SA, $\mathbf{x}_m \in \mathbb{C}^{Ns\times 1}$, is expressed as;

$$\mathbf{x}_m = \begin{bmatrix} h_m[0] & 0 & & h_m[L-1] & & h_m[1] \\ h_m[1] & h_m[0] & \ddots & 0 & \ddots & \vdots \\ \vdots & h_m[1] & & \vdots & & h_m[L-1] \\ h_m[L-1] & \vdots & & & & 0 \\ 0 & h_m[L-1] & & 0 & & \vdots \\ 0 & 0 & \ddots & h_m[0] & \ddots & \\ \vdots & \vdots & & h_m[1] & & 0 \\ 0 & 0 & & \vdots & & h_m[0] \end{bmatrix} \begin{bmatrix} s_0 \\ s_1 \\ \\ \\ \vdots \\ \\ \\ s_{Ns-1} \end{bmatrix} + \begin{bmatrix} n_0 \\ n_1 \\ \\ \\ \vdots \\ \\ \\ n_{Ns-1} \end{bmatrix} \tag{10}$$

Note that this is a time domain expression. Ns represents the sample number of the training signal.

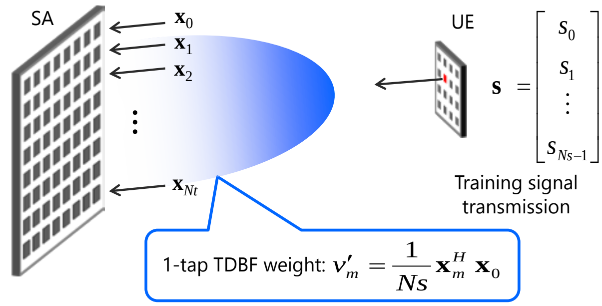


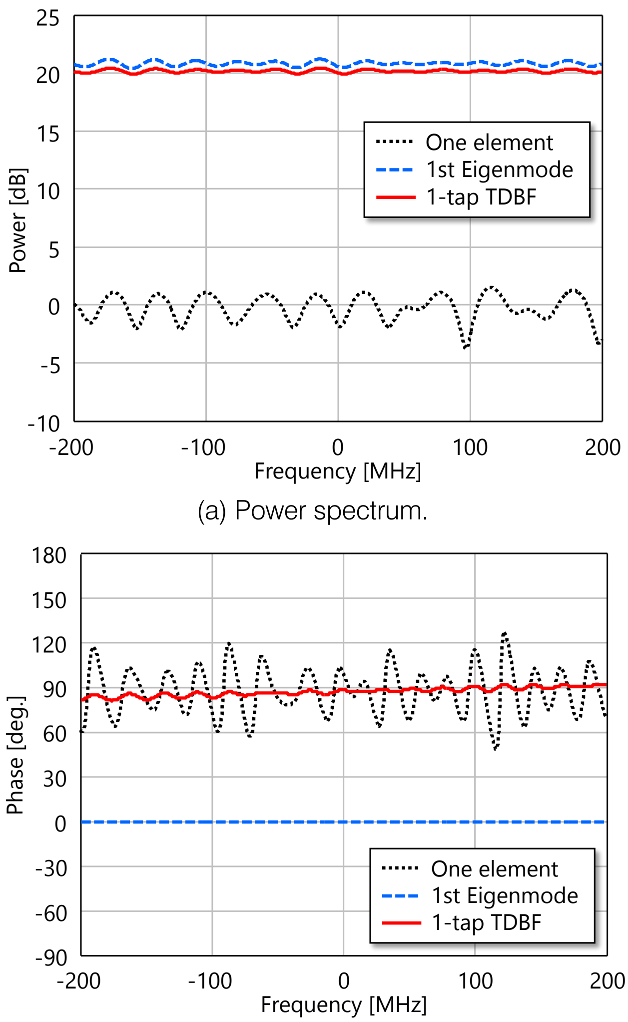
Figure 2 : Proposed 1-tap TDBF

$h_m[l]$ is the l-th (l = 0, ... , L-1) complex path gain of the channel impulse response for the m-th reception antenna element of SA. L denotes the number of paths. s_α and n_α (α = 0, ... , Ns-1) are training signal samples and AWGN components in the time domain, respectively. Eq. (10) assumes cyclic prefix insertion. SA then calculates the maximal ratio combining (MRC) weight [24], v'_m, by correlating the signals received on the m-th and reference antenna elements (here assumes m = 0), in the time domain.

$$v'_m = \frac{1}{Ns}\mathbf{x}_m^H \mathbf{x}_0 \tag{11}$$

TDBF reception weight vector for the i-th SA, $\mathbf{v}'_i = [v'_0, \ldots, v'_m, \ldots, v'_{Nt-1}] \in \mathbb{C}^{Nt\times 1}$, is obtained. Note that reciprocity calibration [25, 26] is required to obtain the transmission weight from the reception weight since uplink and downlink signals go through different circuits. This paper assumes that the processing is ideal. Eq. (11) can suppress the additive noise effect since the received signals for each sample are correlated whereas the noise components are identically independent in the samples. When Ns = 1000 for example, the signal-to-noise power ratio (SNR) can be improved 30 dB and weight accuracy is greatly improved. The weight calculation can work correctly even in low SNR conditions with link budget shortfall and is one of advantages of the 1-tap TDBF scheme. Finally, SA applies the TDBF weight and transmits a training signal to UE. In this process, the SA works as a single virtual antenna with large beamforming gain due to the TDBF weight. Owing to this gain, UE estimates the equivalent channel vector for the virtual single antenna, $\mathbf{H}_{ii}\mathbf{v}'_i \in \mathbb{C}^{Nr\times 1}$ under the improved SNR condition; it can be utilized as MRC weight vector, $\mathbf{u}'^H_i = (\mathbf{H}_{ii}\mathbf{v}'_i)^H$. When BS is composed of multiple SAs, UE identification, e.g. which SA is allocated to which UE, can be controlled by BS in a centralized manner.

To understand the fundamental performance of TDBF, we first evaluate the single antenna UE case in which SA with 121 elements UPA performs TDBF to UE with 1 antenna element. Fig. 3 shows an example of the power and phase spectra. In this figure, red, blue and black lines show the results for proposed 1-tap TDBF,



(a) Power spectrum.

(b) Phase spectrum.

Figure 3 : Fundamental performance of 1-tap TDBF

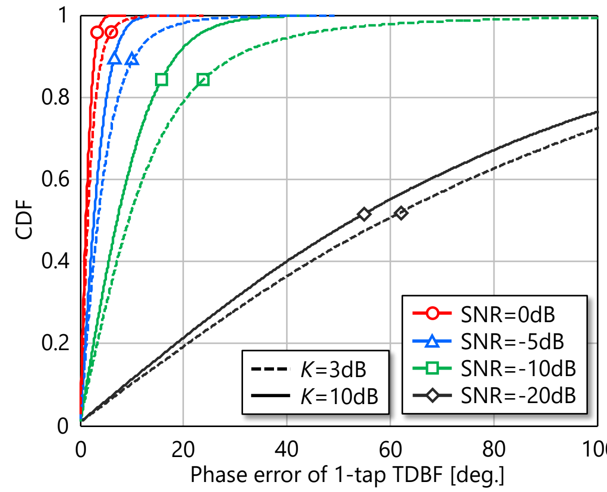


Figure 4 : CDFs of phase error provided by 1-tap TDBF

1st eigenmode, and one element without beamforming, respectively. This evaluation assumes the Rician channel model with K = 10 dB and 16 scatterers are located around UE. The 1st eigenmode transmission, which is equal to maximal ratio transmission (MRT) in this case, is performed for each subcarrier. It attains the beamforming gain calculated as $10\log_{10}(121)$ = 20.8 dB, as shown in Fig. 3 (a). Meanwhile, 1-tap TDBF achieves comparable beamforming performance; the difference is only about 1 dB. It is clear that both beamforming arrangements can compensate the channel distortion unlike the single antenna reception case. When we observe Fig. 3 (b), the phase spectrum without beamforming (i.e. SISO) fluctuates by about 60° due to the multipath components. The 1st eigenmode transmission cancels this fluctuation to 0°. Phase components and frequency components are perfectly aligned. Phase components for TDBF are relatively aligned to that of the reference antenna element. Though the phase spectrum still fluctuates, its variation is really quite small. This yields valuable beamforming performance as shown in Fig. 3 (a).

Fig. 4 plots CDFs of phase error provided by 1-tap TDBF. CDF performance is exhibited with various SNR and Rician K-factor. Assuming Ns = 2048, 1-tap TDBF weight calculation is performed via Eqs. (10) and (11) given SNR conditions. The absolute value of phase error (i.e. angle fluctuation of TDBF weight coefficient) is then obtained by difference from ideal case as SNR = ∞. Note that the SNR is indicated per antenna element, i.e. SISO case. Even though the noisy case such as SNR = -10 dB, phase error can be suppressed to ±30 degrees, corresponding to 1 dB gain loss, with 90% probability.

These confirm that the 1-tap TDBF works well even though it is simple in manner. Though this paper assumes a Rician channel with larger K factor, millimeter wave signals are vulnerable to blockage caused by walls, humans, and so on. In practical environments, the LoS channel always does not exist. The proposed scheme can obtain the beamforming gain corresponding to the strongest and most stable arriving path if the LoS channel does not exist. This mechanism is completely the same as the existing beam training based approach which identifies the optimal beam pattern to achieve the largest gain. In addition, because we assume that several SAs are installed separately as shown Fig. 1, significant site diversity effect can be expected which will improve the probability that direct or quasi-direct paths exist. Table 1 summarizes computation complexities (defined here as the required number of complex multiplications). Here we assume that the number of available subcarriers for user data is Nc. Computation complexity of TDBF is simply derived

Table 1: Computation Complexity

Precoding scheme	Complexity
Proposed 1-tap TDBF	$NtNs$
SVD	$2Nc(NtNr^2 + Nr^3)$

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as $NtNs$ from Eq. (11). That of SVD is taken to be $2NtNr^2 + 2Nr^3$ [27]. Eq. (11) involves only simple multiplications and its complexity is reasonable. On the other hand, SVD requires complex matrix calculation and the computation load becomes excessive in ultra-wideband communication.Results and Discussions

a) System Level Simulation Settings

Simulation parameters are listed in Table 2. BS is composed of 7 SAs, each of which is UPA with 121 antenna elements. As shown in Fig. 1, SAs are spaced at the interval of D. UEs are uniformly distributed in a circular cell with 20 m radius and inter-site distance (ISD) is fixed to 20 m. BS and UE heights are assumed to be 30 m and 1.5 m, respectively. In this evaluation model, SA selects one UE from its own cell to communicate with. Here, the user scheduling effect is simply taken into account by setting the minimum inter-UE distance to be 3 m. Assuming the Rician fading channel with K = 10 dB, the multipath component is modeled as 18 path exponential decay with 2 dB attenuation for each 10 ns in reference to the literature [28]. Free space propagation is assumed. Spatial correlation, i.e. $\mathbf{R}_{tx,i}$, $\mathbf{R}_{rx,i}$, and LoS channel, is also changed according to UE rotation on the horizontal plane as well as its location. CSI is updated every 1.3msec, which corresponds to 200 symbols for the 6.67 μsec symbol duration. CSI estimation error due to receiver noise is excluded in order to evaluate the impact of the beamforming scheme. Transmission and reception weights are determined at each update event. TDBF weight is ideally obtained by correlation of channel impulse response, i.e. $v'_m = \mathbf{h}_m^H\mathbf{h}_1$. This is validated in the Appendix. We compare 2 transmission schemes as follows;

- 1st eigenmode transmission per subcarrier
- Proposed 1-tap TDBF

Here we discuss the transmission beamforming performance of the two schemes above. UE is assumed to perform MRC reception per subcarrier regardless of the scheme.

b) Simulation Results

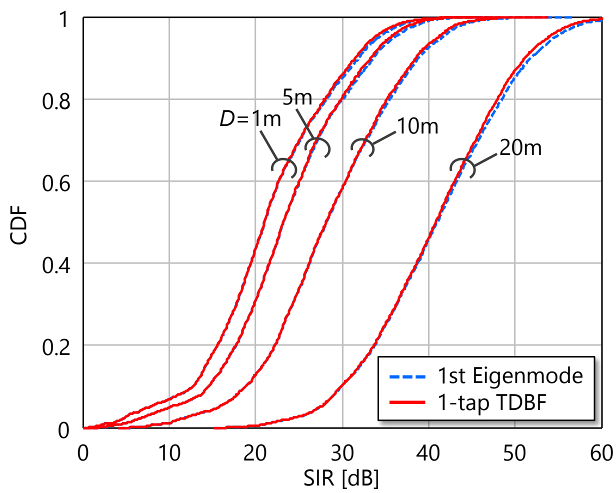
First we investigate how SA spacing impacts the spatial correlation. Cumulative distribution functions (CDFs) of SIR for all UEs are plotted in Fig. 5 for various values of SA spacing, D and Rician K-factor. The CDF plots also include subcarrier-by-subcarrier SIR. In this figure, red and blue lines show the results for 1-tap TDBF and 1st eigenmode, respectively. As this Fig. 4(a) shows, the performance gap between TDBF and 1st eigenmode is quite small and is almost negligible even though 1-tap TDBF is quite simple compared to the 1st eigenmode approach. Increasing D reduces the spatial correlation between SAs and thus SIR of more than 15 dB can be obtained without null steering. When D = 20 m, the SA spacing is equal to the radius of the circular

Table 2 : Simulation Parameters

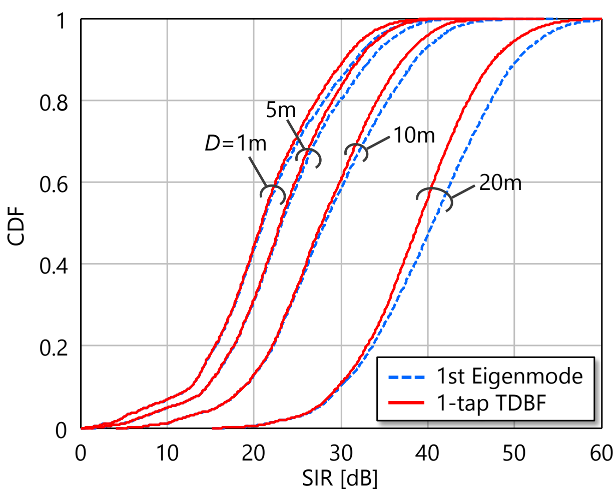
Parameters	Values
Carrier frequency	20 GHz
Bandwidth	400 MHz
Number of FFT points; Ns	2048
Number of subcarriers; Nc	2000
Number of SA antenna elements; Nt	121 (11×11), UPA 0.5λ spacing, HPBW=65°
Number of SAs; Na	7
Number of UE antenna elements; Nr	16 (4×4), UPA 0.5λ spacing, HPBW=65°
Number of UE; Nu	7
Number of stream per UE; Ns	1
Total Transmission power	0 dBm
Antenna gain	0 dBi
Noise power density	-174 dBm/Hz
Propagation model	Free space
Channel model	Rician fading, 18 path exponential decay RMS delay spread: 21.3nsec
Transmission / Reception Angular spread	5° / 5°
Precoding	1-tap TDBF / 1st eigenmode transmission
Post coding	MRC / 1st eigenmode reception
Symbol duration	6.67 μsec
CSI estimation period	1.334 msec (200 symbol)
UE speed	10 km/h ($f_D T_S = 1.2 \times 10^{-3}$)

cell. Each cell is deeply overlapped and UE does not always access the nearest SA. Even in the severe situation, null steering is not necessary for multi-user MIMO communication in these two schemes. The SAs with massive antennas at BS side form narrow beams toward UEs since SAs have wider antenna aperture. Conversely, UEs use fewer number of antenna elements and so have narrow antenna aperture. Their main lobe may significantly impact neighboring SAs. Large D ensures beamforming gain of UE and improves SIR performance in this scheme.

Fig. 5(b) plots CDFs of SIR for K = 3 dB. Distribution characteristics of the 1st eigenmode transmission are almost the same as the case of K = 10 dB. SIR performance of TDBF is slightly degraded compared to 1st eigenmode transmission, especially for SIR values above 30 dB. This is because the phase misalignment of the TDBF weight for each subcarrier becomes large due to frequency selectivity when the effect of multipath component becomes more significant. In other words, the difference between TDBF and the 1st eigenmode transmission is negligible for SIR values under 30 dB. In millimeter wave communication,

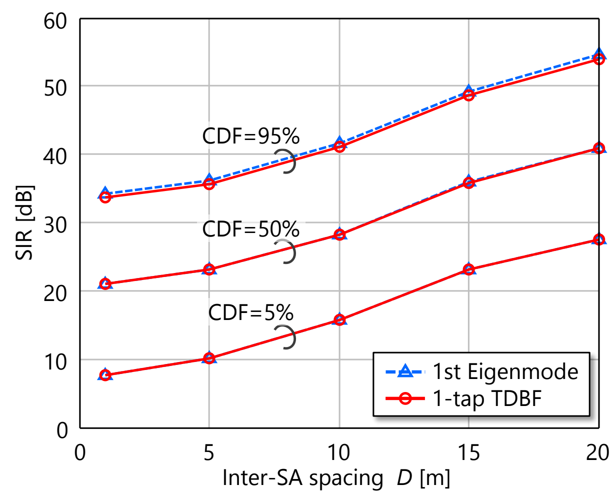


(a) K=10dB.

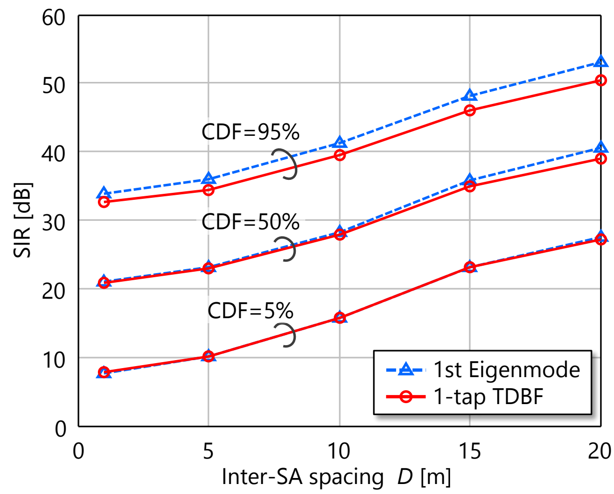


(b) K=3dB.

Figure 5 : CDFs of SIR with SA spacing



(a) K=10dB.

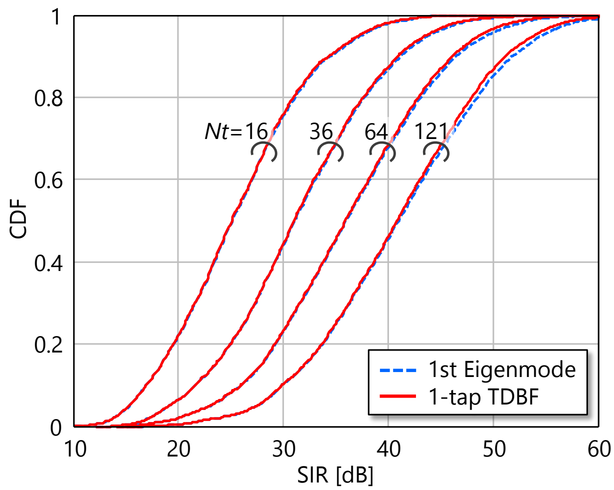


(b) K=3dB.

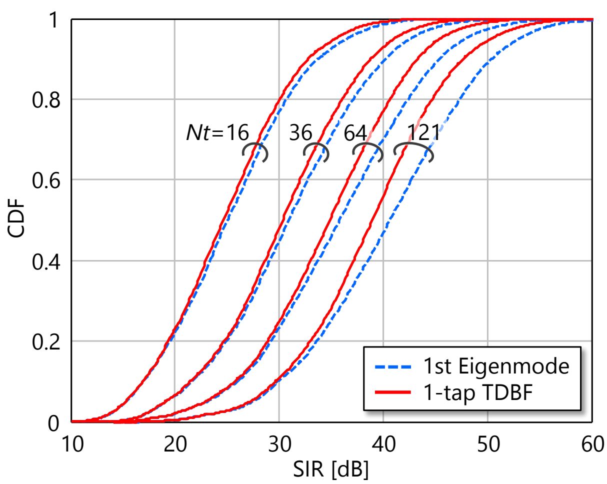
Figure 6 : SIR versus SA spacing

the link budget is poor and high SNR conditions of more than 30 dB cannot be usually expected. Moreover, the large time variation of the propagation channel may break the ideal communication condition. Therefore, TDBF and 1st eigenmode transmission have comparable practical performance even when K = 3 dB. Fig. 6 summarized each representative CDF value with SA spacing. As shown in these figures, enlarging SA spacing is effective in improving parallel transmission performance. In this evaluation model, SA has a small antenna aperture and its main lobe width is not narrow enough to separate UEs that are close neighbors. This inadequate user separation can be compensated by UE beamforming. Though each UE also forms a directional beam, its main lobe width is much wider than that of SA. To ensure user separation, SA spacing should be designed taking account of this effect. In ordinary multiuser MIMO communications, UEs are separated but antennas at BS side are closely installed. By dispersing the SAs, like the UEs, multiuser MIMO can be operated effectively and simply. This is as new multiuser MIMO configuration. The following evaluations employ D = 20 m.

Fig. 7 plots CDFs of SIR with four transmission antenna element numbers per SA; Nt = 16(4×4), 36(6×6), 64(8×8), 121(11×11). Rician K-factor is 10 dB or 3 dB. Note the total transmission power is constant for all Nt values. Increasing the number of antenna elements naturally contributes to enhance beamforming gain, so that SIR performance is rigorously improved. In the evaluation condition, cells are deeply overlapped since the cell radius and ISD are set to 20 m. This includes the situation that a UE does not access the nearest SA. Though it may increase IUI from the nearest SA, desired signal can be greatly intensified due to the large beamforming gain with the large number of antenna elements. In addition, increasing the number of antenna elements enlarges the antenna aperture of SA. This narrows the main lobe width and improves user



(a) K=10dB.



(b) K=3dB.

Figure 7 : CDFs of SIR with number of SA antenna elements

isolation. These effects jointly contribute to obtaining the SIR improvement as presented.

As explained by Fig. 5, the SIR degradation of TDBF relative to the 1st eigenmode transmission can be seen at SIR values more than 30 dB. The performance gap tends to increase with SIR level because the slight phase misalignment of the TDBF weight cannot be ignored at such high SIR values. We introduced the additive noise effect and reevaluated CDFs of SINR performance; see Fig. 8. Using the parameters in Table 2, average SNR is obtained as -1 dB in the SISO case. Millimeter wave communication systems are deployed on the premise of lower SNR condition in SISO channels. Beamforming gain provided by UE/SA antenna array is calculated as $10\log_{10}(16\times121) = 32.9$ dB. This indicates that the performance discrepancy between 2 schemes becomes negligible in terms of SINR since SIR gaps larger than 30 dB are masked by the additive noise effect. By exploiting SA and UE beamforming with massive arrays, the expected desired

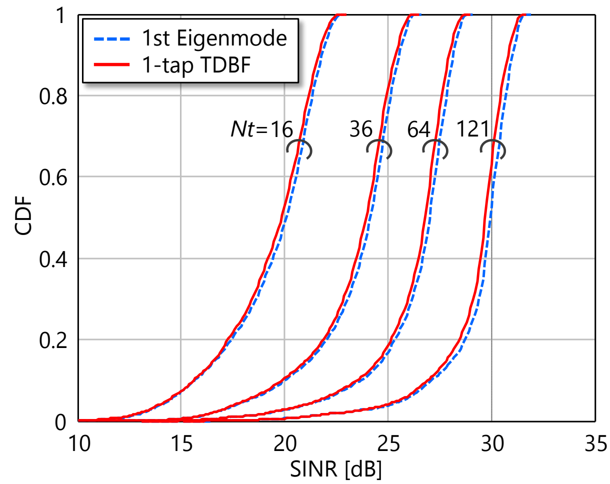


Figure 8 : CDFs of SINR with number of SA antenna elements (D=20m, K=3dB)

signal SNR level is raised to 30 dB. When UE correlation is small, its IUI level can be suppressed significantly under the noise level. The 1st eigenmode transmission cannot eliminate the IUI perfectly due to the absence of null steering. The slight phase misalignment of the TDBF weight also degrades the SIR performance, however, the degree of the phase misalignment is not so large. Therefore, the performance degradation by applying TDBF is negligible in the practical condition.

We evaluated in detail how far TDBF is affected by the NLoS component. CDF = 50% values of SI(N)R with Rician K-factor are plotted in Fig. 9. SIR performance for TDBF is largely degraded as the NLoS component becomes more predominant. However, TDBF can achieve SINR = 28 dB even with K = 0 dB while keeping its degradation relative to 1st eigenmode transmission to within 1 dB. This is still sufficient to provide higher throughput. This result verifies that our approach is effective even in multipath-rich channel environments.

Finally, SIR and SINR characteristics versus UE movement speed are presented. CDF = 5% and 50% value of SI(N)R are plotted in Fig. 10. The most significant feature of the present system embodiment is that SINR performance is basically not affected by UE movement, even in multiuser MIMO communication. In ordinary multiuser MIMO communication, UE movement tends to break null steering triggering significant IUI. As shown in this figure, however, the SIR performance of 1-tap TDBF and 1st eigenmode transmission are not degraded by UE movement. The origin of the good SIR performance of the 2 schemes is the spatial separation of transmission and reception antennas. This reduces the correlation between signal streams and makes null steering unnecessary. This feature offers the significant benefit of reducing the medium access control (MAC) overhead by extending CSI estimation interval. For example, Nv times expansion of UE movement speed is

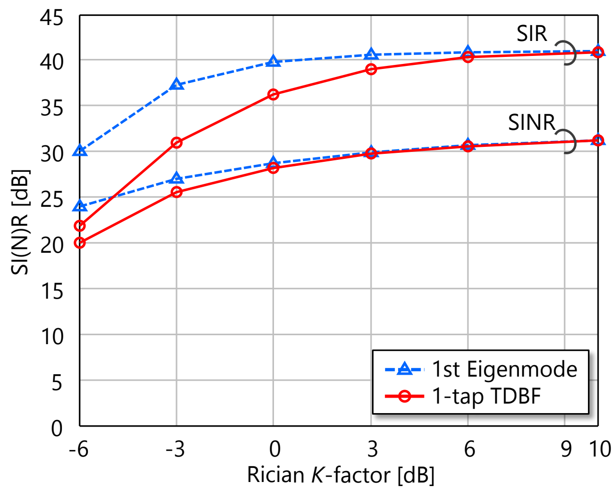


Figure 9 : CDF=50% value of SIR/SINR versus Rician *K*-factor (*D*=20m, *Nt*=121)

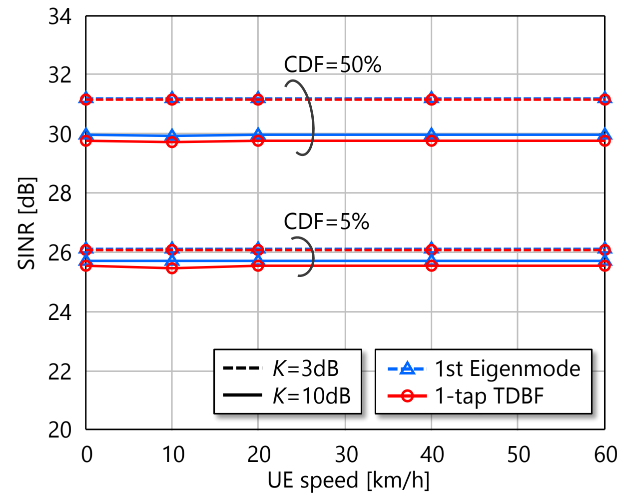


Figure 10 : CDF=5% and 50% values of SINR versus UE speed (*D*=20m, *Nt*=121)

equivalent to *Nv* times extension of CSI estimation interval. Therefore, if the expected UE speed is 4 km/h, it can be read from the figure that CSI estimation interval can be much longer, for example 15 fold, with no performance degradation, which represents a significant reduction in MAC overhead. Increasing the carrier frequency shortens the wavelength and strengthens the effect of UE movement. Meanwhile, separating SAs can de-correlate UEs and suppress the need for null steering in multiuser massive MIMO communications.

c) *Discussions*

For the heterogeneous networks in 5G, decoupling of the architecture control plane (C-plane) and user plane (U-plane) is assumed. With this assumption, all UEs can communicate with both small cell BS and macro cell BS. In a small cell environment, there is no guarantee of having a clear direct path between BS and UE, which may make the performance of our proposed scheme unstable. However, such UEs can communicate with the macro cell BS instead of the small cell BS. The probability of having direct path is expected to be increased by setting isolated SAs with location diversity. In order to effectively offload the traffic from a macro cell to a small cell, a lot of small cells should be scattered over crowded spaces. For this scenario, the deployment cost of the small cell BS should be reasonable, which emphasizes the value of the simplified operation of our proposal. Although our proposal is full digital 1-tap TDBF operation, it can be enhanced to analog BF with partial digital operation because the transmission and reception weights are constant across the bandwidth [8, 14-17]. This enhancement is also effective in reducing the cost as it needs fewer RF components. This paper assumed that each UE communicates with just a single SA, however, it is also possible for plural SAs to communicate with the same UE. In this case, though the correlation between streams for the same UE may become larger, it can be compensated by reception side signal processing between the multiplexed chains. As the result, peak throughput per UE can be more than 10 Gbit/s which meets the 5G target requirement. Its validations will be further investigated.

As discussed above, our proposal has great advantages such as simple implementation and robustness against time varying channels in multiuser spatial multiplexing. It is an attractive candidate for small cell deployment in the 5G world.

IV. Conclusions

This paper verified the effectiveness of multiuser parallel transmission by SA beamforming on massive arrays assuming the LoS dominant channel environment in millimeter wavebands. Computer simulations revealed that valuable SINR gain can be stably attained without null steering when SAs are sufficiently separated in space. The proposal is also robust to channel time variation since null steering is not performed. Additionally, we proposed 1-tap TDBF, which can alleviate complex signal processing of the 1st eigenmode computation as well as suppressing the effect of additive noise on weight derivation. Our simplified and approximate approach achieved performance comparable to that of frequency domain 1st eigenmode transmission as the rigorous solution.

V. Acknowledgement

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Appendix

Defining the channel impulse response as;

$$\mathbf{h}_m = \left[h_m[0] \quad h_m[1] \quad \cdots \quad h_m[L-1] \quad 0 \quad \cdots \quad 0 \right]^T \tag{A1}$$

1-tap TDBF weight coefficient ideally approaches $v'_m = \mathbf{x}_m^H \mathbf{x}_1 / Ns \approx \mathbf{h}_m^H \mathbf{h}_1$ and we utilized this value in the simulations. From Eq. (A1), Eq. (10) can be rewritten as;

$$\mathbf{x}_m = [\mathbf{C}^0 \mathbf{h}_m \quad \mathbf{C}^1 \mathbf{h}_m \quad \cdots \quad \mathbf{C}^{Ns-1} \mathbf{h}_m]\, \mathbf{s} \tag{A2}$$

where $\mathbf{s} = [s_0, \ \ldots\ , s_{Ns-1}]^T \in \mathbb{C}^{Ns\times 1}$. The AWGN term is omitted for simplicity. $\mathbf{C}$ is defined as the row-wise cyclic shift operator;

$$\mathbf{C} = \begin{bmatrix} 0 & 1 & 0 & \cdots & 0 \\ & 0 & 1 & & \\ \vdots & \vdots & 0 & \ddots & \vdots \\ 0 & & & & 1 \\ 1 & 0 & 0 & \cdots & 0 \end{bmatrix} \tag{A3}$$

$\mathbf{C}^\alpha$ performs cyclic shift operation α-times and has the following characteristic;

$$(\mathbf{C}^\alpha)^H = \mathbf{C}^{-\alpha} \tag{A4}$$

Eq. (11) can be derived as follows,

$$\begin{aligned} v'_m &= \frac{1}{Ns} \mathbf{x}_m^H \mathbf{x}_1 \\ &= \frac{1}{Ns} \mathbf{s}^H [\mathbf{C}^0 \mathbf{h}_m \quad \mathbf{C}^1 \mathbf{h}_m \quad \cdots \quad \mathbf{C}^{Ns-1} \mathbf{h}_m]^H [\mathbf{C}^0 \mathbf{h}_1 \quad \mathbf{C}^1 \mathbf{h}_1 \quad \cdots \quad \mathbf{C}^{Ns-1} \mathbf{h}_1]\, \mathbf{s} \\ &= \frac{1}{Ns} \mathbf{s}^H \begin{bmatrix} (\mathbf{C}^0\mathbf{h}_m)^H \mathbf{C}^0 \mathbf{h}_1 & (\mathbf{C}^0\mathbf{h}_m)^H \mathbf{C}^1 \mathbf{h}_1 & & \cdots & (\mathbf{C}^0\mathbf{h}_m)^H \mathbf{C}^{Ns-1} \mathbf{h}_1 \\ (\mathbf{C}^1\mathbf{h}_m)^H \mathbf{C}^0 \mathbf{h}_1 & \ddots & & & \\ & & (\mathbf{C}^\alpha\mathbf{h}_m)^H \mathbf{C}^\beta \mathbf{h}_1 & & \vdots \\ \vdots & & & \ddots & \\ (\mathbf{C}^{Ns-1}\mathbf{h}_m)^H \mathbf{C}^0 \mathbf{h}_1 & & \cdots & & (\mathbf{C}^{Ns-1}\mathbf{h}_m)^H \mathbf{C}^{Ns-1} \mathbf{h}_1 \end{bmatrix} \mathbf{s} \\ &= \frac{1}{Ns} [s_0^* \quad \cdots \quad s_\alpha^* \quad \cdots \quad s_{Ns-1}^*] \begin{bmatrix} \mathbf{h}_m^H \mathbf{C}^0 \mathbf{h}_1 & \mathbf{h}_m^H \mathbf{C}^1 \mathbf{h}_1 & & \cdots & \mathbf{h}_m^H \mathbf{C}^{Ns-1} \mathbf{h}_1 \\ \mathbf{h}_m^H \mathbf{C}^{-1} \mathbf{h}_1 & \ddots & & & \\ & & \mathbf{h}_m^H \mathbf{C}^{\beta-\alpha} \mathbf{h}_1 & & \vdots \\ \vdots & & & \ddots & \\ \mathbf{h}_m^H \mathbf{C}^{-Ns+1} \mathbf{h}_1 & & \cdots & & \mathbf{h}_m^H \mathbf{C}^0 \mathbf{h}_1 \end{bmatrix} \begin{bmatrix} s_0 \\ \vdots \\ s_\beta \\ \vdots \\ s_{Ns-1} \end{bmatrix} \\ &= \frac{1}{Ns} \sum_{\alpha=0}^{Ns-1} s_\alpha^* s_\alpha \mathbf{h}_m^H \mathbf{h}_1 + \frac{2}{Ns} \sum_{\alpha=0}^{Ns-2} \sum_{\beta=\alpha+1}^{Ns-1} \mathrm{Re}\left(s_\alpha^* s_\beta \mathbf{h}_m^H \mathbf{C}^{\beta-\alpha} \mathbf{h}_1 \right) \end{aligned} \tag{A5}$$

If *Ns* is large enough, we can expect,

$$E[s_\alpha^* s_\beta] = \begin{cases} 1 & \text{for } \alpha = \beta \\ 0 & \text{for } \alpha \neq \beta \end{cases} \tag{A6}$$

In addition,

$$\mathbf{h}_m^H \mathbf{C}^{\beta-\alpha} \mathbf{h}_1 = 0 \quad \text{for } \beta - \alpha > L \tag{A7}$$

Therefore, the absolute value of the 2nd term in Eq. (A5) becomes much smaller than that of the 1st term. The following result can be derived;

$$v'_m \approx \mathbf{h}_m^H \mathbf{h}_1 \tag{A8}$$

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Design and Analysis of Low Run-Time Leakage in a 13 Transistors Full Adder in 45nm Technology

By Md.Masood Ahmad, Dr. K.Manjunathachari & Dr.K.Lalkishore
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Abstract- In this paper a new full adder is proposed. The number of Transistors used in the proposed full adder is 13.Average leakage is 62% of conventional 28 transistor CMOS full adder. The leakage power reduction results in overall power reduction. The proposed full adder is evaluated by virtuoso simulation software using 45 nm technology of cadence tools.

Keywords: peak leakage, average leakage, peak power, average power,13transistors full adder, run-time leakage.

GJCST-A Classification: G.4, B.3.2

DESIGNANDANALYSISOFLOWRUNTIMELEAKAGEINA13TRANSISTORSFULLADDERIN45NMTECHNOLOGY

Strictly as per the compliance and regulations of:

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Md.Masood Ahmad [α], Dr. K.Manjunathachari [σ] & Dr.K.Lalkishore [ρ]

Abstract- In this paper a new full adder is proposed. The number of Transistors used in the proposed full adder is 13.Average leakage is 62% of conventional 28 transistor CMOS full adder. The leakage power reduction results in overall power reduction. The proposed full adder is evaluated by virtuoso simulation software using 45 nm technology of cadence tools.

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I. Introduction

In this paper various 1-bit full adders are considered for leakage analysis. A 13 Transistor Full adder is designed and analysed for low leakage. Full adders considered for analysis in this paper are Complimentary MOS implementation of full adder[29], Mirror full adder [29], Transmission gate full adder[29], Manchester full adder[29], Complimentary pass transistor logic full adder, Low power Full adder, Lean integration with pass transistor full adder, 20 Transistor Transmission gate full adder, Improved 14 transistor Full adder, SERF Full adder, GDI XOR full adder, 10 transistor full adder, 9A full adder, 9B full adder, 13A full adder, 8 transistor full adder and proposed 13 transistor full adder. full adders and their implementation style at transistor level includeng the proposed full adder is as follows.

CMOS 28 Transsistor Full Adder: Conventional CMOS Full Adder consists of 28 transistors as shown in fig.1.From the following equations one can design CMOS 28 Transistor full adder circuit[29].

$$C_O = AB + [A + B]C \quad (1)$$

$$S = ABC_i + C_O(A + B + C_i) \quad (2)$$

Mirror Adder: The fig.2. shows Mirror Adder. An improved adder circuit, also called as "Mirror Adder"[2]. This is a clever implementation of the propagate/generate/delete function when either D or G is high, CO is set VDD of Gnd, respectively. When the conditions for propagate are valid (or P is 1), the incoming carry is propagated to CO.

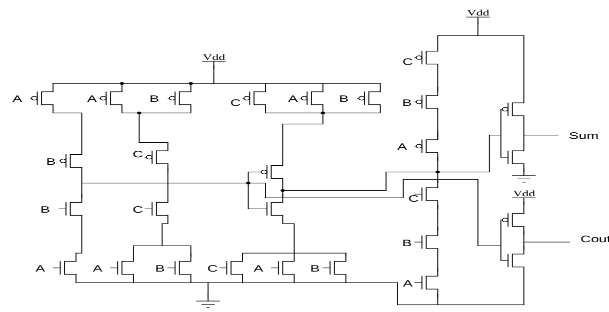

Figure 1: Transistors Full Adder

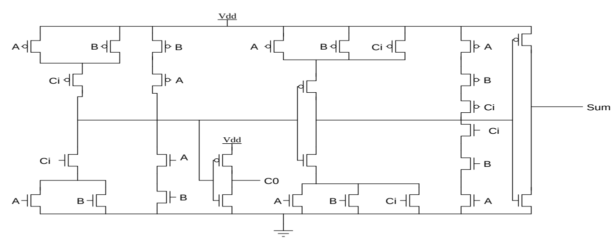

Figure 2: Mirror Adder[29]

Transmission Gate Full Adder: A full adder can be designed to use MUX and XOR. While this impractical in a complementary CMOS implementation, it becomes attractive when MUX and XORs are implemented as transmission gates[4] .The Transmission Gates Full Adder is as shown in fig.3.

Manchester Full Adder: The main idea of designing this adder is to optimize carry chain till some extent in TG full adder by adding generate and delete signals[5]. The propagate path is unchanged, and it passes Cin to the Cout output if the propagate signal is true. If the propagation condition is not satisfied, the output is either pulled low by Di signal or pull up by Gi. Manchester Full adder[29] as shown in fig.4.

Complimentary pass transistor logic: The CPL Full Adder has 18 transistors[33] and is based on NMOS passtransistor logic as shown in fig.5 and fig.6.

Low Power Full Adder: This novel adder [43] cell has 16 transistors. It is based on the 4-transistor implementations

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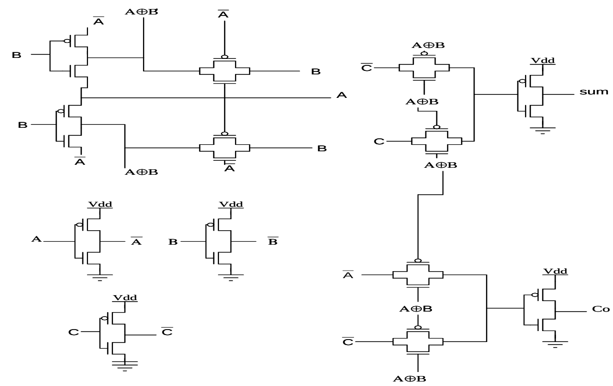

Figure 3: Transmission Gates Full Adder[29]

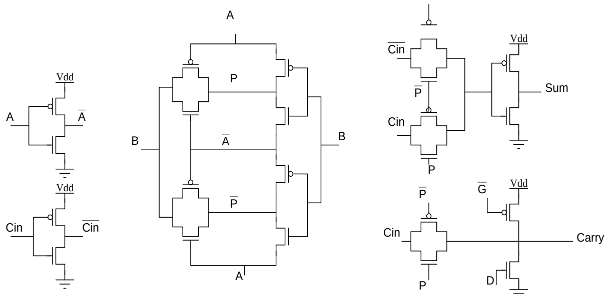

Figure 4: Manchester Static Full Adder[29]

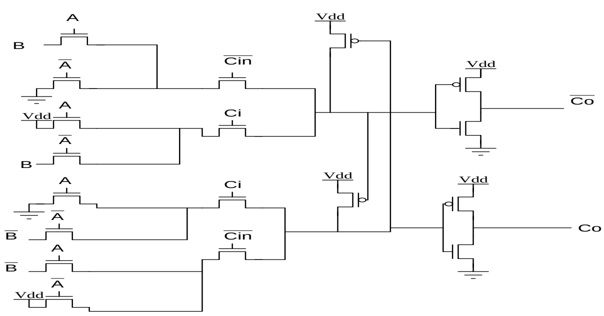

Figure 5: Complementary Pass Transistor Logic Full Adder[33]

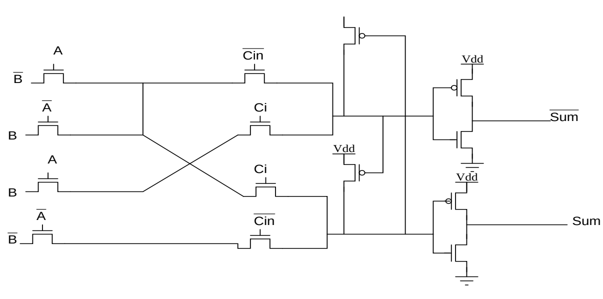

Figure 6: Complementary Pass Transistor Logic Full Adder[33]

of the XOR and XNOR functions.The LP adder is as shown in fig.7.

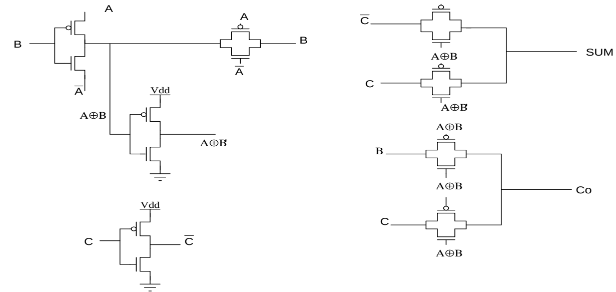

Figure 7: Low Power Full Adder[43]

LEAP Full Adder: The pass transitor based cell library and synthesis tool are constructed to clarify the potential of top down pass transistor logic. The entire scheme is called LEAP[43] (Lean Integration with Pass-ransistor).The LEAP Full adder is as fig.8.

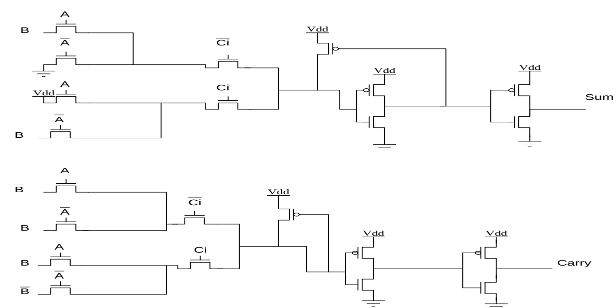

Figure 8: LEAP Full Adder[43]

20 Transistor Transmission Gate Full Adder: Transmission gate approach[36] which is another widely used CMOS design style to implement digital function has been discussed. Transmission gate based implementation is similar to pass transistor with the difference that transmission gate logic uses NMOS and PMOS transistors where as pass transistor logic uses only one type of transistor i.e. either NMOS or PMOS. 20 Transistor Transmission Gate Full adder is as shown in fig.9.

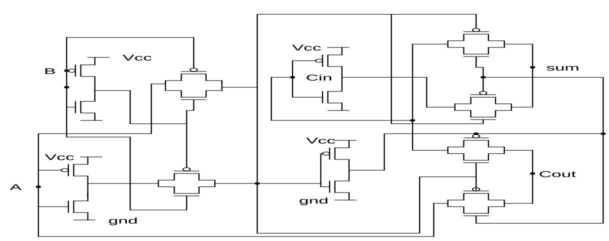

Figure 9: 20T Transmission Gate Full Adder[36]

Improved 14 Transistor Full Adder: The 14T full adder [40] contains a 4T PTL XOR gate an inverter and two transmit ssion gates based multiplexer designs for Sum and Cout signalsas shown in fig.10.The circuit is simpler than the conventional adder. This circuit has 4 transistor XOR which in the next stage is inverted to produce XNOR. These XOR and XNOR are used simultaneously to generate Sum and Cout.14 Transistor full adder is as shown in fig.10.

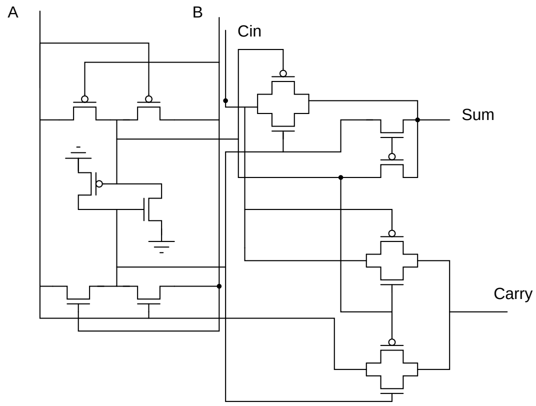

Figure 10 : 14T Full Adder[40]

SER Full Adder: SERF adder[11] reuses charge by the energy recovering logic and hence consumes less power than non-energy recovering logic. SERF adder has no direct path to the ground, therefore power dissipation is reduced. The charge stored at the load capacitance is reapplied to the control gates. The joint effect of these two things makes the SERF adder an energy efficient design.SERF Full adder as as shown in fig.11.

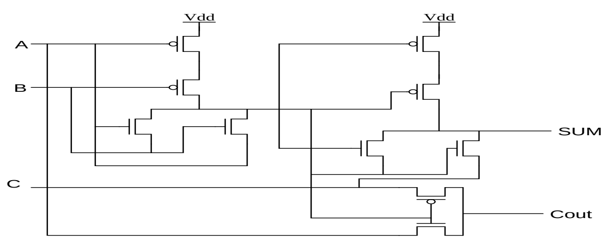

Figure 11: Static Energy Recovery Full Adder[11]

GDI XOR Full Adder: GDI[39]technique is implemented to design a high performance and low power full adder.GDI cell contains three inputs- G (common state input of NMOS and PMOS), N (input to the source or drain of NMOS) and P (input to the source or drain of PMOS). GDI XOR Full adder as shown in fig.12.

10 Transistor Full Adder: Full adder using 10T uses more than one logic style for the implementation and it is called as Hybrid logic design style. The number of transistors count is 10. 10 Transistor Full adder[41]is as shown in fig.14.

9A Full Adder: The 9A Full adder[38] shown in below figure implemented using four transistor static energy recovery XNOR, four transistor ground less XNOR and 2:1 multiplexer. 9A Full adder as shown in fig.15.

9B Full Adder: It resembles the inverter-based XOR but the difference is that the Vdd connection in the inverter based XOR is connected to the input A. Since the new XOR gate has no power supply, it is called Powerless XOR, or PXOR. A new XNOR gate is named as Groundless XNOR or GB

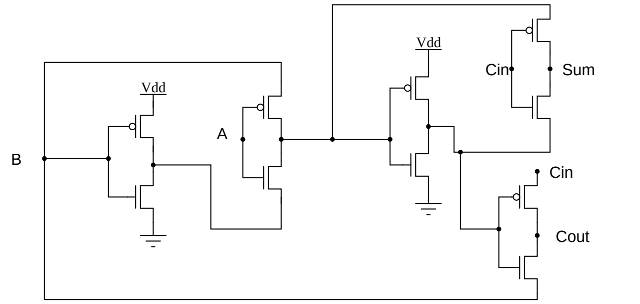

Figure 12: Gate diffusion XOR Full Adder[39]

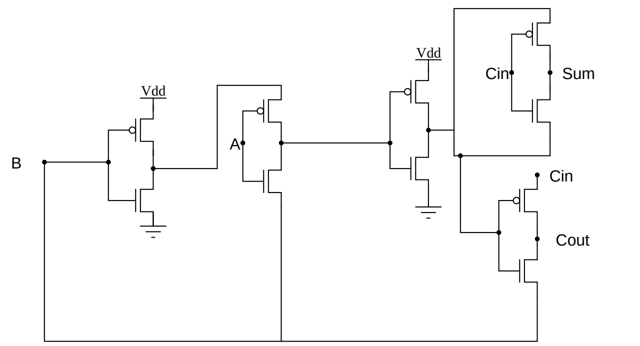

Figure 13: Gate diffusion XNOR Full Adder[39]

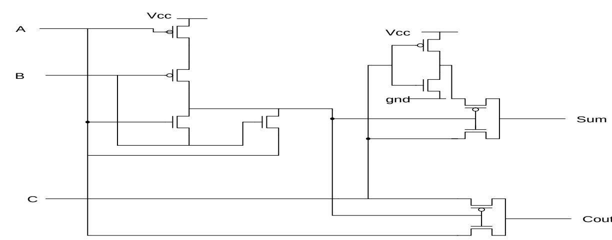

Figure 14: 10T Full Adder[41]

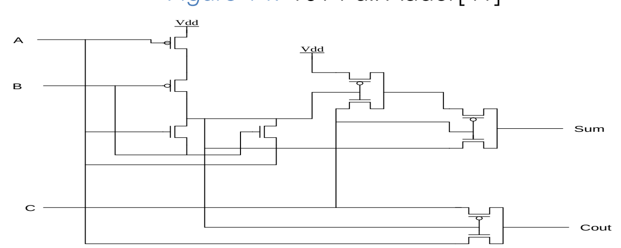

Figure 15: 9A Full Adder[38]

XNOR because there is no direct connection with ground.9B Full adder[38] is as shown in fig.16.

13A Full Adder: The other type of 10 transistors 1- bit full adder is 13A full adder, which have better critical delay than the 10 transistors SERF full adder in all loading conditions. 13A adder[11]comes out as best when compared with respect to low power and delay. 13A adder is built using SERF XNOR and INV XNOR. The

Cout is designed using multiplexer.13A Full adder is as shown in fig.17.

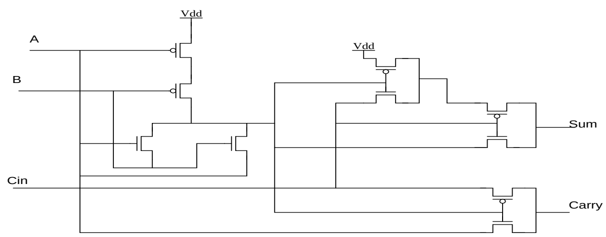

Figure 16: 9B Full Adder[38]

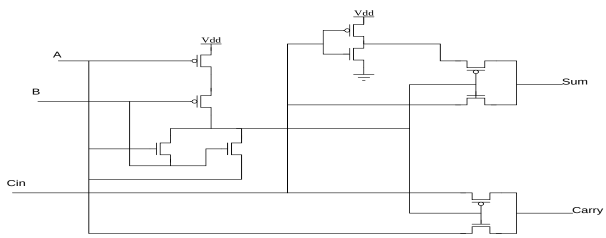

Figure 17: 13A Full Adder[11]

8 Transistor Full Adder: It is built using three multiplexers and one inverter[42]. The inverter in the circuit speeds up propagation of Cout and also provides complemented Cout signal required for generation of Sum. The xor gate is replaced by xnor gate. So the need for inverter is avoided. This reduces the transistor count to 8. The transistor level implementation of the eight transistor full adder is shown in fig.18.

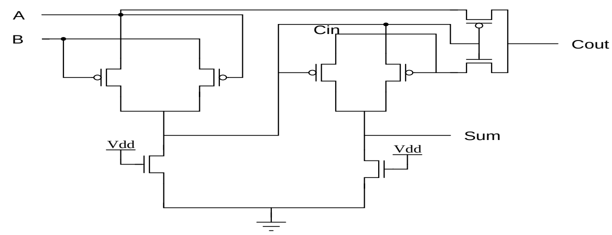

Figure 18: 8T Full Adder[42]

Proposed 13 Transistors Full Adder: After having detail analysis we started to work by undertaking different approach so that we can reduce leakage till some extent along with increase in swing and reduce in average power. Then initially we started on investigating on output swing and came to know that by replacing A_B it is possible to increase the swing as well as decrease in leakage along with average power. It differs from complementary CMOS in that the source side of the MOS transistor is connected to an input line instead of being connected to power lines. Another important difference is that only one PTL network (either NMOS or PMOS) is sufficient to perform the logic operation. In this circuit sum is calculated from output carry. This proposed full adder resulted low leakage as well as low power as comparing with existed full adder.

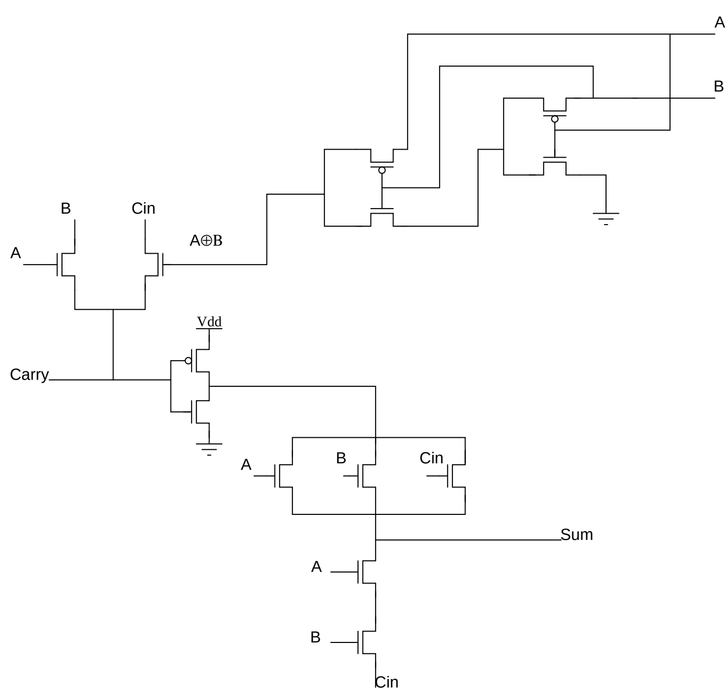

Figure 19: Proposed 13T Full Adder

II. Simulation Results

Simulation results are presented in table I for the analysis. The table I shows the comparision of average leakage power, peak leakage power, average power and peak power in 28 Transistor full adder, Mirror, TG, Manchester, CPL, LEAP, 20T, 14T, SERF, GDI XOR, GDi XNOR, 10T, 9A,9B, 13A, 8T and proposed 13 Transistors full adders.

Table 1: Comparison Of Proposed Full Adders With Existing Full Adders

Full Adders	Average Leakage	Peak Lekage	Average Power	Peak Power
28T	313.2nW	34.83uW	351.1nW	36.26uW
Mirror	288.3nW	37.48nW	317.0nW	28.75uW
TG	8.9uW	53.80uW	41.96uW	69.14uW
Manchester	9.01uW	76.24uW	42.32uW	115.32uW
CPL	27.86uW	72.52uW	39.83uW	63.03uW
LP	9.13uW	44.14uW	35.19uW	54.44uW
LEAP	29.05uW	73.88uW	38.42uW	73.75uW
20T	11.91uW	44.62uW	24.05uW	41.31uW
14T	7.04uW	18.6uW	720nW	51.89uW
SERF	2.03uW	33.31uW	14.5uW	29.55uW
GDI XOR	158nW	10.90uW	252nW	24.56uW
GDI XNOR	151.8nW	15.53uW	330.4nW	16.18uW
10T	7.83uW	31.97uW	12.55uW	31.90uW
9A	12.48uW	24.96uW	116.1nW	29.35uW
9B	85.78nW	33.95uW	12.45uW	27.39uW
13A	8.8uW	38.14uW	21.17uW	43.03uW
8T	15.76uW	34.95uW	20.36uW	31.91uW
Proposed 13T	196.4nW	17.10uW	12.67uW	52.70uW

III. Conclusion

Below 70 nm technologies run-time leakage power dominates the dynamic power.So one should come up with new full adder which consumes less leakage power compared to dynamic power one such attempt is discussed in this paper.

IV. Acknowledgment

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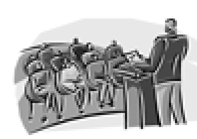

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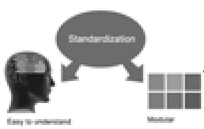

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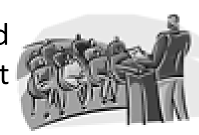

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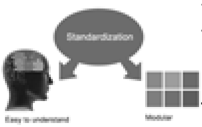

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- Significant conclusions or questions that track from the research(es)

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Approach:

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	A-B	**C-D**	**E-F**
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Introduction	Containing all background details with clear goal and appropriate details, flow specification, no grammar and spelling mistake, well organized sentence and paragraph, reference cited	Unclear and confusing data, appropriate format, grammar and spelling errors with unorganized matter	Out of place depth and content, hazy format
Methods and Procedures	Clear and to the point with well arranged paragraph, precision and accuracy of facts and figures, well organized subheads	Difficult to comprehend with embarrassed text, too much explanation but completed	Incorrect and unorganized structure with hazy meaning
Result	Well organized, Clear and specific, Correct units with precision, correct data, well structuring of paragraph, no grammar and spelling mistake	Complete and embarrassed text, difficult to comprehend	Irregular format with wrong facts and figures
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