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Analysis of the Success and Failure Connection in The Advanced Access Class Barring for Internet of Thing Deployment over LTE-Advanced Network

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Abstract

LTE-Advanced is one of the latest generations of mobile communication systems that supports, beside voice and data communication services, the Internet of Things and machine-to-machine communication services. Collisions occur during radio access, due to an increased request of the uplink channel, and have negative impact on the quality of service. The 3GPP has proposed for this purpose, among others solutions, the Access Class Barring to alleviate the problem. In our previous work, we have proposed the Advanced ACB (A-ACB) that significantly reduces the collisions responsible of the congestion in LTE-A network. The A-ACB combines congestion detection method that we have proposed, with the 3GPP native ACB. The simulations results have showed that A-ACB gives much better results compared to basic ACB. Furthermore, it is less complex and easy to implement and does not require large investments from network operators. In this paper, we propose the detailed analysis of the collisions and connection requests success events that occur in the network in the context of an increased request of the uplink channel, during radio access. The methodology is based on mathematical modeling of the collision detection of UEs. The simulations are operated considering 1000 terminals candidates to network access. The results obtained show that the collisions and success requests during UEs connection to the network are randomly distributed among UEs. The originality of this work resides in the fact that it shows not only the detailed distribution of the collisions of the UEs but also shows the image of this distribution.

Keywords
LTE, Random Access Process, Internet of Things, Access Class Barring, Congestion.

1. Introduction
The concept of smart cities refers to an urban environment where all everyday objects communicate and exchange data and information with each other without human intervention. These objects are used in various fields such as e-health, smart grids, e-learning, e-libraries, telemedicine, traffic management, environmental management, smart transport systems, etc. The establishment of a smart city entails the deployment of a very large number of connected objects. Different technologies such as wired networks, local short range wireless networks, sensor networks and cellular wireless networks have been studied to allow massive Machine Type Communication (MTC) applications

like Internet Of things (IoT). However, because of the mobility of some equipment and for the sake of efficiency and also, to ensure a good quality of service, some equipment must be directly connected to the LTE-A mobile network. The LTE-A is a mobile network standard that have benefits such as good mobility, good accessibility, good coverage, good security, broadband and many other features that are very important for M2M applications and services. Since the LTE-A network was primarily designed for typical Human-to-Human (H2H) communication, it is clear that adaptations must be made to meet the requirements of M2M communication. In recent years, studies have shown that the Random Access (RA) procedure is not effective for managing massive M2M communication within the LTE network, as the LTE random access physical channel (PRACH) would suffer of overload when a large number of UEs are competing for accessing resources *(L. Ferdouse & al, 2015)*, *(A. Laya & al, 2014)*. The massive deployment of M2M devices leads to congestion of the radio access and core network of the LTE system. 3GPP, which is the organization responsible for standardizing mobile networks, including LTE, has identified and proposed some solutions to solve the problems and requirements which may arise when integrating M2M devices into LTE network *(A. Laya & al, 2014)*. Overload and congestion control in the LTE radio access network (RAN) is considered by 3GPP as a high priority issue that must be addressed to enable M2M communication over the LTE network. Overload and congestion on the network normally occur when a large number of access requests are sent by devices to a single base station during the random access procedure (RACH procedure). The RACH procedure has a very low efficiency when the number of devices increases *(K. Zheng & al, 2014)*. In this paper, we analyze UEs connection failure when Advanced Access Class Baring (A-ACB) *(G. M. Bouba & al, 2020)* is applied in the LTE-A network. considering 1000 UEs randomly distributed into a unique cell under a single base station, in a transient scenario of massive access of M2M terminals. The remaining of the paper is organized as following: in section II, we present the context of the M2M communications for IoT in LTE environment, the random-access procedure and congestion; in section III, we present the method based on Advanced ACB system model; the section IV presents the simulations results and the discussions. The conclusion is presented in section V.

2. Context

2.1 Lte-A Random Access Preambule

In order to be able to access the network, the UEs must make the request from the base station by sending a preamble via the PRACH channel. Preambles are digital "signatures" broadcasted at regular time intervals by the base station. They are generated from the sequences of the Zadoff-Chu algorithm, and include a cyclic prefix CP, a sequence and a guard time (GUARD TIME) as shown in Figure 1.

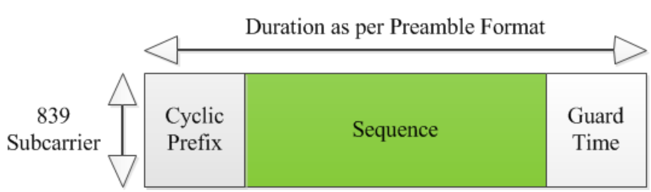


Figure 1. Structure of random-access preamble

$$x_x(n) = exp\left[-j\frac{\pi un(n+1)}{N_{zc}}\right], n \in [0, N_{zc} - 1\,] \qquad (1)$$

Where u is the root index of the ZC and N_{ZC} is the length of the ZC sequence.
ZC sequences have an ideal cyclic autocorrelation property that can be given by equation (2):

$$r_{uu}(\sigma) = \sum_{n=0}^{N_{ZC-1}} x_u(n)x_u(n+\sigma) = \delta(\sigma) \qquad (2)$$

Where $x_u(n+\sigma)$ is the cyclic shift version of $x_u(n)$ with an offset σ.
The random-access preambles are obtained from a ZC sequence with different cyclic offsets. More precisely, the number of preambles per ZC sequence is given by equation (3):

$$N_p = \frac{N_{ZC}}{N_{CS}} \qquad (3)$$

Where N_{CS} is the size of the cyclic shift.

In FDD-LTE, N_{ZC} and N_{CS} are respectively 839 and 13, which means that the number of available preambles per ZC sequence is 64. The eNB reserves some preambles called N_{Cf}, for specific contention free RA accesses, and allocates separate preambles to different UEs. The other remaining preambles ($64 - N_{Cf}$) are used for random access with contention. Each UE randomly uses one preamble. During contention free access, the connection is initiated by the base station which, at the same time, provides the UEs with the necessary resources. This is applied to priority communications such as emergency alert messages and specific uses. In the case of contention access, UEs compete for the remaining 54 preambles in the RACH process. The ZC sequence is largely detailed in *(L. Atzori & al , 2010) (3GPP TS 24.368, 2016) (3GPP TS 36.321, 2013).*

2.1 Random access procedure

The LTE's Medium Access Control (MAC) function is divided into two parts: contention access known as RACH and contention free access. Contention access is a process initiated by the idle terminals (Radio Resource Control standby mode RRC) to request access to the uplink channel, necessary for the transmission of packets. However, contention free access is designed for active UEs (RRC connected mode). Only the active UE can transmit data. If an UE is in idle mode, it must first proceed to the RACH process *(O. Kodheli & al. 2021) (Ziyang Li & al. 2020)* for an initial connection to the network.

The contention based random access is explained by the fact that at each access time interval granted by the base station, the UEs must compete for a random-access preamble to perform network access request. The random-access process is divided into four stages (Figure 2):

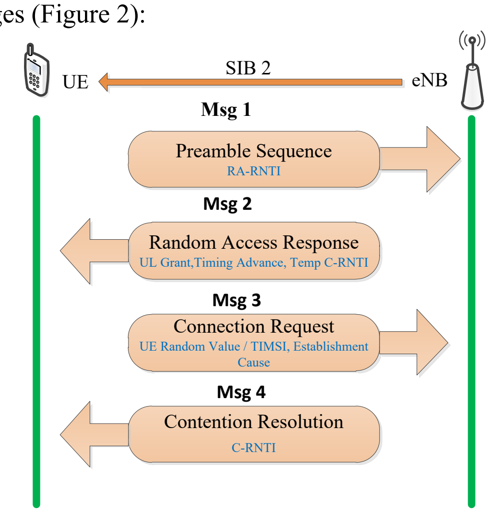


Figure 2. Random Access process

2.3 Rach congestion

The RACH procedure has been identified by 3GPP as a difficult task *(A. Lo & al. 2011)* for M2M communications, due to the sudden increase in signaling traffic. This is caused by a sudden increase of the number of UEs trying to simultaneously access to the same base station. This situation may be for example a result of smart meters suddenly becoming active at the same time, after a period of power failure or alerts, following any kind of disaster.

As a result, massive access requests from UEs can overload the PRACH channel, leading to an increase of contention probability which, in turn, will increase access time and failure rate. So, the network will be congested. One of possible solutions to reduce PRACH load is to increase the number of scheduled access opportunities per frame. But this produces a reduction of the number of resources available for data transmission, and therefore a contraction of the uplink channel data transport capacity occurs. Furthermore, it is to be known that the total amount of Random-Access resources which can be allocated in an LTE-A frame is limited. Finally, the processing of the Zadoff-Chu sequence, which is used to generate preambles, is more expansive time computationally and may be an additional source of problems for resource limited devices, such as MTCs.

When two or more UEs send the same preamble during a single Random-Access Opportunity (RAO), a collision occurs. The eNodeB can detect a collisionless preamble transmission with a certain probability, P_d, which depends on several parameters, such as the transmission power of the UE. UEs which do not receive Msg2 (see fig 2.) in the Random-Access Response Window (Random Access Response Window) should increase their power and retransmit a new preamble randomly selected in a new RAO. The base station can detect collisions based on the difference in transmission delays of these preambles in step 1, then it will not send any response for this preamble (step 2); the concerned UEs will then be led to resume the operation. However, if the concerned UEs are equidistant from the base station, the collision will not be detected; therefore, a copy of the response from step 2 will be sent to them. In this case, the collision is resolved by the contention resolution message in step 4. Only the selected UE will receive the response in step 4 and will be granted to access the network. The UEs which have not received the response in step 4 declares access failure and plans a new access attempt, meaning restarting the preamble transmission process. Each UE has a preamble transmission counter which is incremented after each unsuccessful attempt. When the counter reaches the preamble preambuleTransMax (broadcasted by the eNodeB in the SIB2 message), the UE declares the network unavailable and then, the failure of the RA is signaled to the upper layers and terminates the random-access process *(3GPP TS 36.321, 2015), (3GPP TS 36.331, 2015), (R. Cheng & al. 2015), (3GPP TS 36.213, 2015)*.

3 Method

3.1 System model

During the RACH process under a low load network environment, the success rate of requests is very high with low delay. But, as soon as a heavy load is felt, this rate decreases very quickly to reach a critical threshold, and the delay with. This can continue until reaching levels that no longer allow the network to guarantee a good quality of service. In this paper we analyze the performance of A-ACB proposed in *(G. M. Bouba & al, 2020)*, a model for overload detection that allows the network to anticipate this situation, in order to enable it to set up the overload resolution solution. The detection method consists in providing the network (base station) with informations about the state of the use of the resources, i.e. the number of preambles used that we name R_{used}, and the threshold from which the collisions become important as calculated in [B. G. Mahamadou & al. 2018] and named R_{limit}. Then, when R_{limit} is reached, i.e. $R_{used} \geq R_{limit}$, the ACB is then activated in order to decongest the network. The ACB will remain active until the number of preambles used falls below the R_{limit} i.e. $R_{used} < R_{limit}$. At that point ACB is disabled.

$$R_{used} = R\left(1-\left(1-\frac{1}{R}\right)^{N}\right) \qquad (4)$$

Where:
R : is the total number of preambles;
R_{used} : is the total number of used preambles;
N : is the total number of UEs.

Figure 3 shows the plots of used preambles versus successful preambles according to the equation (4) and equation (9) from *(B. G. Mahamadou & al 2018).*

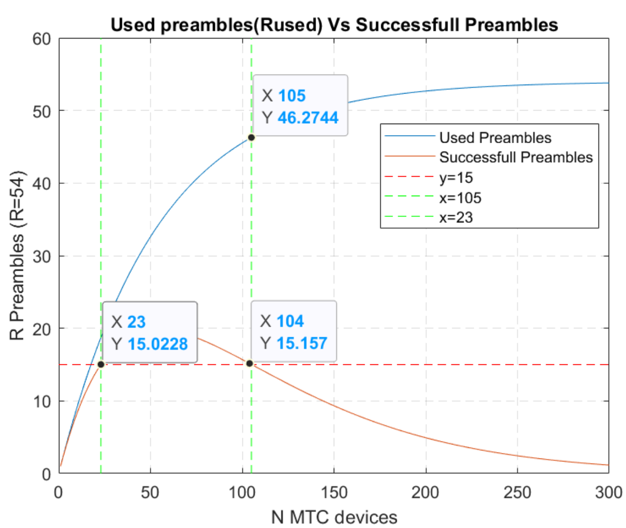


Figure 3. Used preambles vs successful preambles

The flowchart of A-ACB is given in Figure 4

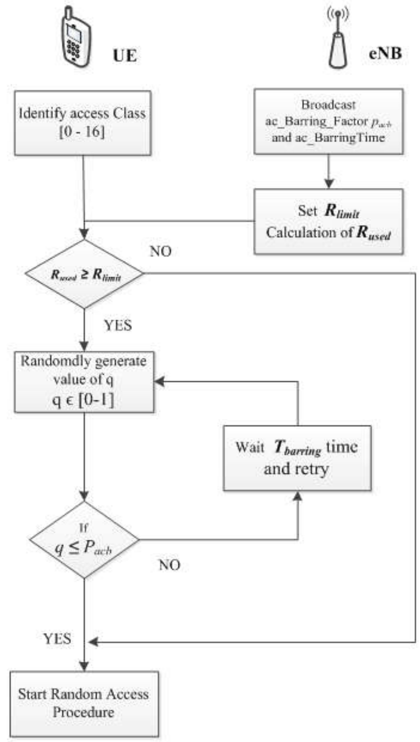


Figure 4. Flowchart of A-ACB *(G. M. Bouba & al, 2020)*

4. Simulations, Results and Discussions

4.1 Results obtained in previous work

Before to present the detailed analysis of UEs access failure to the network, we recall the results obtained in the previous work for a best comprehension. We have first evaluated the performance of collisions detection method A-ACB algorithm. We have set the number of available preambles to be used for estimation R in each RACH opportunity slot to 54, the probability factor *p* is set to 0.6, and the overload detection parameter R_{limit} is 46 *(G. M. Bouba & al, 2020)*. The RACH system model is as described in section III, and the arrival of UEs follows the time limited beta distribution as indicated in 3GPP TR37.868.

We have computed this distribution for n = 1000 UEs. The goal is to quantitatively estimate the distribution of the UEs likely to access the network and the UEs likely to undergo request collision. Figure 5 presents the obtained results. The distribution presented in the figure show that for n = 1000 UEs trying to access the network simultaneously, 171 UEs belong to the group likely to be successfully get access and 829 UEs belong to the group likely to undergo collisions. To highlight the randomness of the distribution of UEs, we have repeated the computation of distribution, and the results are presented in Table 1. We observe that the distribution of UEs likely to get successful connection and those likely to undergo collision is random. However, we notice that the average number of the UEs likely to get successful connection to the network is 171 and the average number of those which likely to undergo collisions is 829. The standard deviation calculated for the each of the two groups of UEs is 0.8165. We may conclude that these distributions have the same standard deviation, which may be taken as 1 UE.

Table 1. Distribution of UES in the success and the collisions of connection *(G. M. Bouba & al, 2020)*

i^{th} computation	1	2	3	4	5	6	7	8	9	10
Success distribution	171	172	170	172	170	171	171	170	171	172
Collisions distribution	829	828	830	828	830	829	829	830	829	828

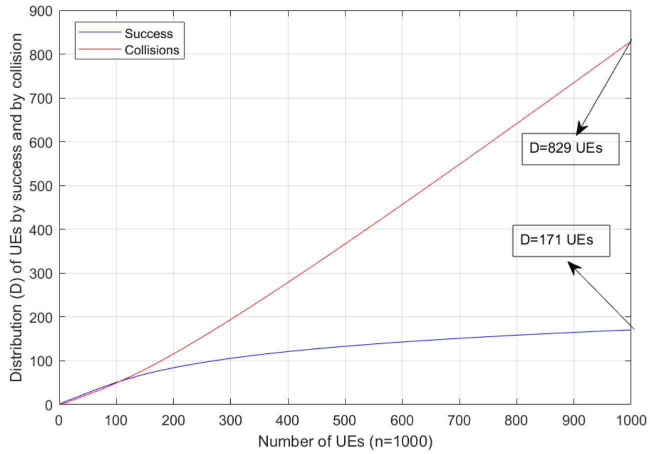
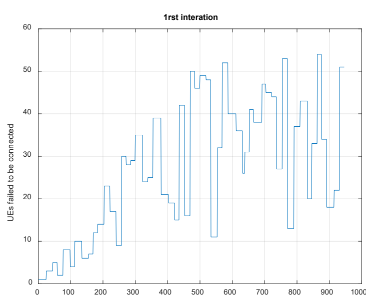


Figure 5. Distribution of UEs by success connection and by collisions *(G. M. Bouba & al, 2020)*

4.2 Results of the detailed UEs connection failure

Due the results presented in Figure 5, we analyze the number of UEs that failed to access to the network. We have operated six iterations when A-ACB is enabled where at each iteration, failures are identified and represented. Considering 1000 competing UEs for network access, failures are represented in figures below. Figures 6a to 6l present the obtained results. Figures 6a, 6c, 6e, 6g, 6i and 6k represent the failed access UEs versus all the UEs attempting to access the network and figures 6b, 6d, 6f, 6h, 6j and 6l present the image of these UEs. In the first iteration, out of 100 UEs, less than 10 UEs experience a failure when attempting to access the network. This figure increases to 30 for 300 UEs and around 50 for 1000 UEs attempting to access the network, as shown in Figures 6a and 6b.



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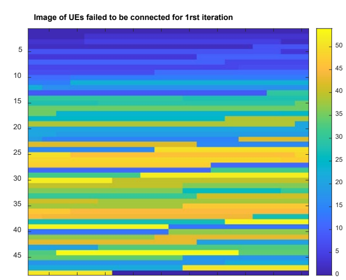

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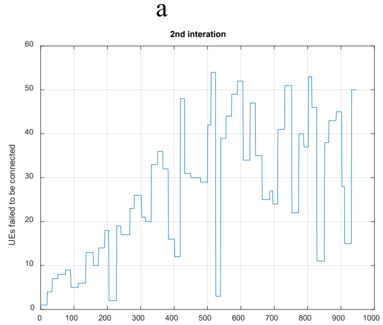

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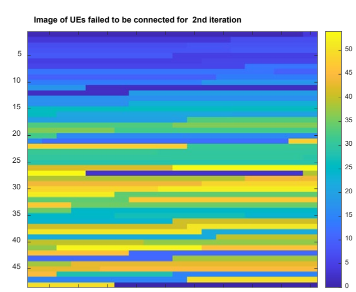

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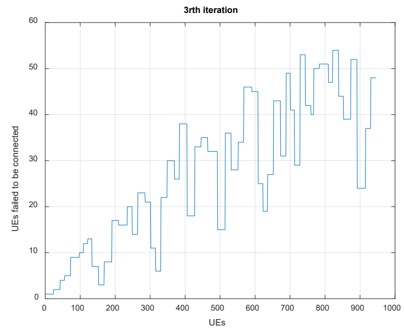

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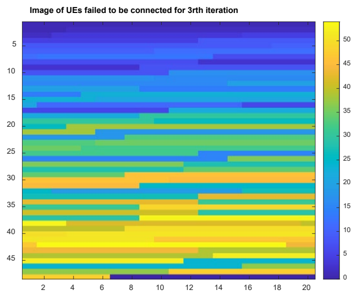

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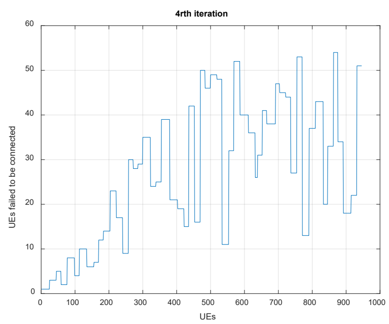

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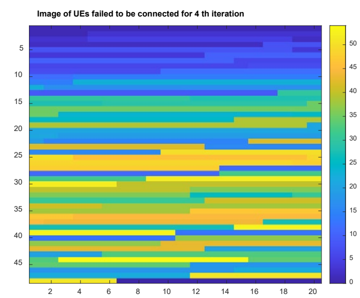

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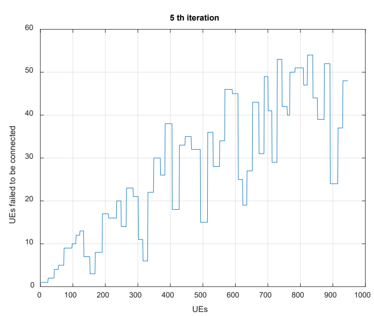

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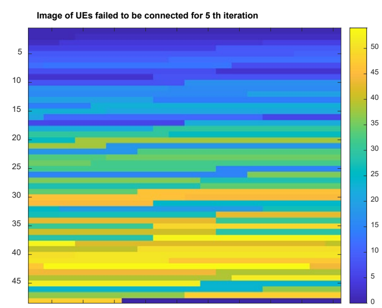

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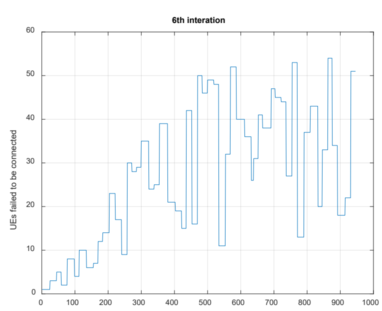

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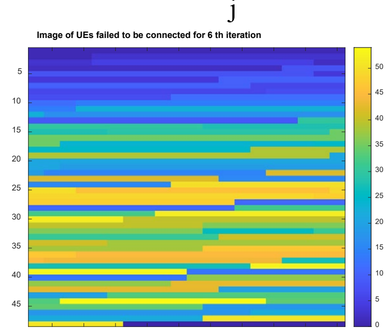

l

Figure 6. UEs failed to be connected

The second iteration shows some similarities to the first in that the number of network connection failures remains below 10 per 100 UEs attempting to access the network using the A-ACB algorithm. This figure increases to around 30 failures for a number of UEs ranging from 300 to 400 UEs, and finally stabilizes at around 50 failures for a total number of 1000 UEs (see Figures 6c and 6d).

By increasing the number of iterations (see Figures 6e, 6f, 6g, 6h, 6i, 6j, 6k, 6l), we obtain approximately the similar results in general, but particularly, the third and the fifth iterations give the same results. This allows us to say that A-ACB achieves an acceptable failure rate in the context of the massive objects competing for network access.

5. Conclusion

In this paper we investigate the detailed analysis of the collisions event that occurs in the LTE-A network communications in the context of an increased request of the uplink channel, during radio access, when Advanced ACB (A-ACB) is activated. Simulations show that A-ACB can minimize the failure rate, or at least stabilize it at a relatively reasonable level compared to the native 3GPP ACB described in 3GPP TR37.868, even in the presence of a large number of UEs. Furthermore, the detailed analysis allows the best comprehension of random character of the UEs access to the network in the context of increasing connected devices. In our further works we plan introduce the application of AI-tools together with MTC communication system for improving the efficiency of the radio access process in LTE-A mobile network system in order to reduce congestion.

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Pr. MBAINAIBEYE Jérôme has received the Master degree in Signal Processing and the PhD degree in Electrical engineering at the National High School of Engineers of Tunis, Tunisia, University of Tunis El Manar in October 1997 and July 2002 respectively. He was an Assistant Professor in the department of Computer Science at the Faculty of Sciences of Bizerte, Tunisia from 2002 to 2007. From May 20 to June 20, 2003, he was a scientific visitor at "ÉQUIPE SIGNAL et IMAGE of Ecole Nationale Supérieure d'Electronique, d'Informatique et de Radiocommunication de Bordeaux (E.N.S.E.I.R.B), University of Bordeaux I, France. In 2008 he has joined the Faculty of Applied and Exact Sciences in the University of N'djamena, Chad, as an Assistant Professor in Electrical Engineering. Since April 2012, he has joined the Polytechnic High Institute of Mongo (Chad) as Director General. In February 14th, 2017, he has joined the University of Doba (Chad) as Rector. In julet 2023, he is the President of the University of Moundou, Chad. Since July 2014, he is an Associate Professor of Electrical Engineer. He is member of Signal, Image and Pattern Recognition Laboratory of the National High School of Engineers, Tunis, Tunisia and an associated researcher in XLM Signal, Images and Communication laboratory department, University of Poitiers, France. He has published several papers in scientific journals and in international conference proceedings. He also has served as a reviewer of the IEEE International Conference on Sciences of Electronics, Technology of Information and Telecommunications SETIT'2007, the International Conference on Document Analysis and Recognition, ICDAR' 2007, the IEEE 3th International Conference on Information & Communication Technologies: From Theory to Application, ICTTA' 2008 and the ELSEVIER Optic & Laser Technology Journal. His research activities include Digital Signal Processing, Image Processing, Image Analysis, Image and Video Compression, Communication Technologies, Wavelet Transform and its applications, Biometric systems and applications, Medical image processing, Renewable energy.