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# BANDWIDTH PROVISIONING SCHEME FOR 3D WIRELESS SENSOR NETWORKS

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## ABSTRACT

Bandwidth (BW) resources are scarce and valuable in Wireless Sensor Networks (WSNs). Managing this scarcity in BW is a key challenge in WSN's environments. Achieving high BW utilization (BWU) will rise the Quality of Service (QoS) that network can guarantee, without the omission of the importance of concurring BWU, with the minimizing of connection blocking (CBP) and dropping (CDP) probabilities. This paper considers attaining high QoS from point of BW scheduling whether WSNs is designed in two or three dimensions, also our scheme studies the effect of existence or the absence of base station blind spot. We have tested WSN under sixteen different cases, which comprised: Two Dimension structure (2D), 3D structure, Indoor space (Is), Outdoor space (Os), without Blind Spot (nBS), with Blind Spot (wBS), using static borrowing mechanism (SBBS), and finally using dynamic borrowing mechanism (DBBS). The results revealed that considering network with using dynamic borrowing scheme and with rate up to 50 connection rate (CR) will have better QoS guarantees. Moreover, we can summarize that 3D space outperforms 2D space in general view. Finally, not considering BS and building network outdoor will have better QoS guarantee in general. In addition, it is worth mentioning that previous results are processed from repetition each situation 2500 times, which make these results high strict and reliable.

**Keywords:** *Borrowing Scheme, Connection Blocking Probability, Connection Dropping Probability, Connection Rate, 2D structure, 3D structure, Blind Spot, Indoor Space, Outdoor Space.*

## 1. INTRODUCTION

A wireless sensor network is a network which consists of devices called sensors. These sensors cooperate with each other to monitor physical or environmental conditions; node in a WSN is typically supplied with a radio transceiver, or other wireless communications device, a small microcontroller, and battery which are usually the energy source [1].

ZigBee is one of wireless standards which is a technology developed as an open global standard to address the unique needs of low-cost, low-power, wireless sensor networks. The standard takes full advantage of the Institute of Electrical and Electronics Engineers (IEEE) 802.15.4 physical radio specification, and operates in unlicensed bands worldwide at the following frequencies: 2.400–2.484 GHz, 902-928 MHz and 868.0–868.6 MHz. There are sixteen channels between 2.4 and 2.4835GHz, ten channels between 902.0 and 928.0MHz, and only one single channel between 868 and 868.6MHz [2].

The term QoS in cellular networking field refers to resource reservation control mechanisms rather than the achieved service quality. To have QoS in desired range-many challenges should be exceeded, such as: mobility of hosts, scarcity of BW, and channel fading, to overcome these challenges, many Wireless Cellular Networks (CWNs) parameters must be taken into consideration, these parameters are: Bandwidth utilization, End-to-end delay, Jitter, Blocking probability(BP), and Dropping probability(DP)[3].

Term handoff in cellular telecommunications refers to the process of transferring data session or an ongoing call from one channel connected to the core network to another. Handoff is classified to inter-cell handoff,

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and intra-cell handoff, another classification is: hard handoff, and soft handoff [4].

BW depends on the overall effectiveness of the antenna through a range of frequencies, so all of these parameters must be understood to fully characterize the BW capabilities of an antenna. One of these characters is antenna blind cone (BC) which can be defined as the volume of space that cannot be scanned by an antenna because of limitations of the antenna radiation pattern and mount. In BC the signal power is almost zero. As a result, any connection exist in this spot cannot receive any signal, so it will be dropped by the Handling Mobile Switching Center (MSC). Therefore, BC should be considered as an effective factor in BWU [5].

In recent years almost all research works in routing protocol at WSNs were interested in energy efficiency factor because energy is rare and should not be scattered. But when imaging and video sensors have been used and when growing in demand certain end-to-end performance guarantees another factor was appeared, this factor is QoS [6]. In Mobile Ad-hoc NETworks (MANETs) several new protocols have been proposed for QoS routing with taking the dynamic nature of the network into consideration. On the other hand, there are little researches done in QoS for WSNs especially for three dimensional WSN [7,8].

The rest of this paper is organized as follows: In Section 2 related works will be presented; our work will be introduced in Section 3. Simulation environment and the related results taken from the simulation will be presented and evaluated in Section 4. Section 5 gives the conclusions and suggests the future work.

## 2. RELATED WORKS

In [3], they proposed a Rate-Based Borrowing Scheme (RBBS) in which the size of the reserved pool is fixed at a certain percentage of the total amount of available BW in the cell, in contrary to previous work where the size of pool is determined by requests from neighboring cells. In RBBS, the primary drawback is that there is pre-allocation of resources, which will definitely lead to waste BW.

Another work is Dynamic Rate-Based Borrowing Scheme (DRBBS) which has been designed in CWNs [9]. Dynamic Rate-Based Borrowing Protocol is a modification to RBBS scheme, and it avoids pre-allocation of resources. The DRBBS was tested in a simulation that considered a 2D cellular network. Coverage area in simulator was partitioned into seven cells.

Concept of 3D was introduced to QoS for CWNs in [10]. In this paper, authors adopted the DBBS as in [9] but they take into consideration the antenna properties, such as: 3D propagation for radio frequency signal, and the existence of BS in an area close to the base station base. Three-Dimensional Dynamic Rate-Based Borrowing Scheme (3D-DBBS) in the CWN has nine cells.

## 3. PROPOSED SCHEME

In this section, we explore in details our proposed scheme which we called an Adaptive Three-Dimensional Dynamic Rate-Based Borrowing Scheme (A3D-DBBS). Our scheme aims to increase the BWU in WSNs, and to decrease CBPs and CDPs. Also, we study WSN under new cases which give us a vision about performance of this type of network and how it submits to these new conditions. Hence, we did this scheme to improve QoS, that WSNs can guarantee, and to find best structure for this type of networks. In [10], they designed 3D-DBBS scheme for CWNs, while our scheme is designed for WSNs. Also, 3D-DBBS has nine cells in its 3D structure while on the contrary our 3D structure has 21 cells. On the other hand, there are many similarities between 3D-DBBS and our scheme, such as: borrowing mechanisms, BWU, BS, CBP, and CDP. Our scheme concentrates on total BW scheduling, on available BW distributing on current connections, and on QoS guaranteeing which is required by each connection. Many factors will be considered in designing this scheme, like: CBP, CDP, Handoff connections, new connections, coverage area space whether 2D or 3D, Indoor environment, Outdoor environment, existence or absence of BS, and most importantly the borrowing mechanism.

Here are some features of our proposed Scheme: sensors move in 3D environment, so each region - excepting outer regions of network- has twenty neighboring regions. To imagine the network architecture, let's suppose area X , where X has two neighbor regions, one is above it and the other is below it (two vertical neighbors). Also X is surrounded by six regions (six Horizontal neighbors), each region of them has region above it

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and another one below it. So X has also (twelve diagonal neighbors), hence any interior region has twenty neighbors. Our conception for 3D WSN is shown in Figure 1.

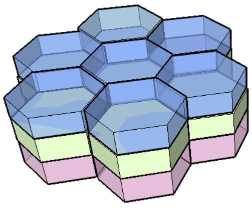

*Figure1: Wireless Sensor Network in A3D-DBBS*

To ensure that our scheme is suitable for WSNs, we modified values that measure base station capacity and that measure desired BW for each connection depending on special needs for sensor. Every cell has one base station which can supply connections with 4000 Kbps, where we determined this value by: choosing ZigBee standard with 2.4 GHz band, this band has sixteen channels, each channel of them has data rate equal to 250 Kbps. So, sixteen channels will have 16 * 250 Kbps= 4000 Kbps.

Connections may be originated in Base station cell space (called new connection) or come from neighbor cells (called handoff connection). Base station is responsible for scheduling BW between connections to have maximum BWU as possible. Our study concerns about sensor wireless networks with these assumptions:

- Sensors are mobile, and we will not be concerned about routing algorithm inside the cell, clustering mechanism, and energy consuming. On the other hand, we will focus only on Handoff operation between different cells, dropping and blocking probabilities, and BWU during roaming.
- Each cell has one fixed base station which is responsible to collect data from sensors in its cell, and is responsible to transmit collected data to Gateway through other cells, and also it is responsible to schedule BW for its sensors and any sensor entering its cell. Our scheme will concern only with last mentioned job.
- All regions have equal probability of receiving new and handoff connections.
- Use concept of borrowing BW from existing connections to accept both new and handoffs connections.
- This idea is useful in environment that needs to be sensed in 3D and with real time multimedia vision.
- Our scheme will use IEEE 802.15.4 or ZigBee standard for Radio Frequency (RF) to transmit data. We choose ZigBee standard to manage communication between sensors due to its specification [2]. ZigBee has three frequency bands, and because our work is done for multimedia data packets, we preferred to choose the wider band with highest data rate which is equal 2.4 GHz. Then, we dropped MICAz specifications into our imitation base station, because it is the most suitable for our study. MICAz is one of Crossbow products [11].

We use two mechanisms for borrowing BW. The first one is the Static borrowing mechanism. The other is the Dynamic borrowing mechanism which was presented in [9]. Any sensor should provide three parameters when it requests a new connection in a given cell, these parameters are: the desired amount of BW for the connection, the average acceptable amount of BW, and the minimum acceptable amount of BW.

At setup time, every connection should supply its origin cell with two values for its need of BW, first value is called maximum desired BW (M), and the second one is the minimum acceptable BW (m). Loss tolerance of the connection could be defined as the difference between M and m. Also each connection has a local parameter called f, f ($0 \le f \le 1$), this parameter represents the fraction of the BLT that a connection may have to give up in the worst case. Accepting a new connection means that the cell is able to supply this connection with its need of BW and it will not fall below a certain level that is called MEX. By definition, MEX = M – fx(M-m). For more details see [9]. Another cell parameter, Lambda λ, is used. The BLT is divided into shares. Each share is equal to fx(M-m)/λ. Lambda represents the number of steps for degradation in BW from maximum to minimum during borrowing operation.

Low-bit-rate ZigBee networks suffer from challenges in video encoding. The theoretical rate of the underlying IEEE 802.15.4 standard is 250 kbps. Because of the CSMA/CA technique, the realistic maximum is on the order of half the theoretical rate. In practice, it is possible to achieve upwards of 60 kbps with large packet sizes in a low configuration and without considering security. Implementing an advanced codec can yield higher compression ratio which leads to increase the frame-rate while transmitting images over ZigBee [12]. So, we found that the proper value for

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Maximum desired BW (M) in WSNs could be equal 60 Kbps, the average BW could be equal 30 Kbps, and the minimum BW (m) could be equal 10 Kbps. Also, we assigned different values to Lambda to find the most suitable one. Also, we decided to neglect the effect of the signal-to-noise ratio which gives our study pure results of our metrics effects, which will be mentioned in details later.

In our study, we examined network under various transmission rates to reflect the behavior of network under heavy and light connections. Connection rate varied between zero to two hundred connections per one simulation round. On the other side, antenna has in maximally a BS area equal to one tenth of its coverage area; and since every connection is considered as a point, it is obligatory that it will have two coordinates (x2 ,y2). These coordinates are signs to determine if connection is in or out of BS area. The judgment is done by calculating the distance between connection and base station (d). The distances in 2D and in 3D are calculated by Euclidean distance equation (1) since it is always a straight line distance between two points.

$$d = \sqrt{(\Delta x)^2 + (\Delta y)^2} \quad (1)$$

Where: (x1 ,y1 ) are the coordinates of BS,
Δx = x2 – x1,
Δy = y2 - y1.

Similarly, connection and base station have three coordinates for each one (x1, y1, z1) and (x2, y2, z2) in 3D space, the distance between them is shown in Equation (2).

$$d = \sqrt{(\Delta x)^2 + (\Delta y)^2 + (\Delta z)^2} \quad (2)$$

Where: Δx = x2 – x1,
Δy = y2 - y1,
Δz = z2 - z1.

Our scheme study QoS in WSNs under sixteen different cases, which are summarized in Figure 2. Here are some assumptions that we considered while building our scheme:

1) The data rate of the radio does not differ whether the mote is transmitting Outdoor or Indoor. The radio will keep on sending; the problem is whether or not any other nodes will receive the data packets.
2) Applying different connection rates up to two hundred, although we recommend only up to fifty motes per one base station. Anything greater than that will be congestion within the network. Up to fifty nodes that are all trying to send data at any given time will cause data packets to be dropped.
3) In our scheme the only difference between Indoor and Outdoor cases is the radius of cell. We supposed the radius of Indoor cell is equal to thirty meters, while it is equal one hundred meters in Outdoor cases. These are realistic values taken from MICAz base station that is produced by Crossbow Company.

## 4. NETWORK SIMULATOR

Our simulator is designed in Java language; it can simulate networks with up to thousand homogeneous nodes. The aim of this simulator is to examine WSN under different cases while taking in consideration BW availability, and disregarding the effect of BER. Our work takes only the difference in frequency range between Indoor and Outdoor. We divided the simulation study samples into two groups; this helped us to trace different scenarios and conditions. The first group of simulations done for Indoor network structure, the other group tested Outdoor networks. Inside each group we divided the simulations depending on borrowing mechanism whether dynamic or static. In every mechanism we tested 2D and 3D spaces. Finally, each space of them was tested in two cases: wBS, and nBS.

For A3D-DBBS, we use similar simulation setup parameters for all simulation study cases, including: total BW in base station, maximum desired BW for one connection, average BW for one connection, minimum acceptable BW for one connection, lambda λ, fair factor f, Indoor cell radius, Outdoor cell radius, and finally maximum CR. Also, we use different simulation setup parameters for each simulation study case. We will clarify these parameters individually. Tables1 and 2 show the simulation study parameters for all cases.

*Table 1: Simulation Setup Parameters for all cases*

| Parameter | Value |
|---|---|
| Total Bandwidth | 4000 Kbps |
| Maximum Bandwidth | 60 Kbps |
| Average Bandwidth | 30 Kbps |
| Minimum Bandwidth | 10 Kbps |
| Maximum connection rate CR | 200 |

*Table 2: Parameters for different simulation Setup cases*

| Parameter | Value |
|---|---|
| Indoor cell radius | 30 m |
| Outdoor cell radius | 100 m |

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| | |
|---|---|
| Reserved BW for handoff connections in Static mechanism | 1330 Kbps |
| Reserved BW for handoff connections in Dynamic mechanism | 0 Kbps |
| Number of cells in 2D structure | 7 cells |
| Number of cells in 3D structure | 21 cells |

In order to get consistent results, we used same connection rates for each simulation study case. The connection rate value varied between (0-200). This is because the effect of network engaged is a serious factor in all study cases. On other side, the type of connection whether new or handoff was randomly chosen. Also, cell election for generating a new or handoff connection was chosen in a random way. For that, we take in consideration many matrices, they are: 1) The number of connections which measures the number of connections that exist in the network, the purpose of this metric is to show how much network is engaged, and to show the effect of low and heavy load in BWU, CBP, and CDP. 2) The value of Lambda which determines the size of connection share portion. We used this metric to yield different sizes of connection share, and to study its effect on the BWU, CBP, and CDP. 3) The value of fair factor which determines the amount of BW that can be borrowed by other connections, so we expect that when *f* is larger, then the blocking and dropping will be decreased, while BWU will be increased. 4) The size of blind spot, in our simulator we diversify the size from 0% to 10 % of whole area or volume of cells to emphasize its role.

## 5. RESULTS AND DISCUSSION

Comparing between any two cases (A, B) in our simulator is calculated by finding the percentage difference which has the following equation, but it should be notable that case A always presents the case with higher average (see Equation 3).

$$pDiff = ( [avg(A) - avg(B)] / avg(A)) * 100\ \% \quad (3)$$

Where: avg (A) >= avg (B), pDiff: the percentage difference, avg(A): the average of Case A, avg(B): the average of Case B.

It is worth mentioning that each situation in our simulator was repeated 2500 times, making our results highly trustworthy. Also, Al-Sharaeh, in his work on 3D-DBBS (Al-Sharaeh, et al. ,2008), had results with percentages very close to ours. This convergence gives a sign that our simulator results could be considered as contribution.

### 5.1 Indoor and Outdoor Results and Discussion

We start by testing Indoor 2D-WSN with absence of BS, this case has two sub-cases: one is using Static borrowing scheme, and the other is using Dynamic borrowing scheme. Simulation results indicate that Dynamic mechanism is better than Static in Indoor 2D architecture with nBS. Also, it show that Dynamic achieves 97% on average for BWU, while Static has 91% on average. Moreover, results display that Dynamic has 14% while Static has 23% for CBP. In addition, Dynamic obtains 19% on average, but Static obtains 25% on average for CDP. Furthermore, simulator designates that Dynamic loses supremacy for keeping CDP at least when CR is up to 50. Static is more efficient in heavy-load networks, since Static reserved pool of BW for handoff connections. Also, result show that BWU is upper in nBS, and probabilities for CBP and CDP are lower with two mechanisms when neglecting existence of BS. Results of Indoor 2D-nBS cases revealed that Static mechanism achieved 6.5% BWU less than Dynamic mechanism. Also, CBP and CDP in average are better in Dynamic than Static by 8.6% and 5.8%, respectively. Similar behavior can be noticed when the simulation takes in consideration the BS presence. Moreover, simulator showed that Dynamic surpassed Static by 9.1% for BWU, and by 5.7% for decreasing CBP, and by 4.9% for decreasing CDP. We notice that the existence of BS increases the difference between two mechanisms in BWU and decreases it in CBP and CDP. So, we can infer that Static mechanism is more affected negatively by existence of BS. Simulation test for cases mentioned earlier (Indoor 2D-nBS, and Indoor 2D-wBS) were repeated, but this time for 3D environment. Simulator showed that In Indoor 3D structure with no BS, Dynamic still surpasses Static in: increasing BWU, and decreasing both CBP and CDP. More details about results percentages will be mentioned later. In contrary to Dynamic in 2D case, Dynamic in 3D structure overcomes Static all the time by having less CDP. The reason behind this conversion in Dynamic behavior is the nature of our 3D structure which has 21 cells while 2D has 7 cells. This inequality means that coverage area is larger, then same number of connections (whether network is 2D or 3D) is distributed in 21 cells rather than 7. So, cell opportunity to have connection is less in 3D. Hence, connection in 3D becomes more fortunate to have its requirements of BW and not to drop or block which means that 3D

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with Dynamic borrowing mechanism is preferred when looking for high QoS. Similar to pervious cases BWU is also in the interest of Dynamic (explanation is the same as in previous cases) when network is 3D-Indoor with existence of BS. In few words, we can say that the space of network whether it is 2D or 3D has observable effects. Simulation without considering BS shown that Dynamic scheme outperformed Static by 6.6% for BWU on average, also Dynamic decreased CBP by 9.4%, and CDP by 1.3% comparing with Static. On the other hand, simulation results with considering BS show that Dynamic scheme has better utilization for BW by 4.9%, and has fewer probabilities for connections blocking and dropping by 5.2% and 9.7% respectively.

Second group of our simulator is done for Outdoor networks. Simulation results for this group are very closely to results for Indoor simulation results. This is because we only consider radius as a difference between two networks, and we neglect RF interference which is more in Indoors. Interferences yield from some factors like: wireless routers, cube walls etc. Outdoors is a bit better especially if the nodes are line of sight.

### 5.2 Detailing Comparison Results

In this section, we view detailing comparison result between all cases of our simulation runs. We use our own synopses to express all cases (Observe Table 3).

*Table 3: Legend keys*

| | |
|---|---|
| I : Indoor | B: With Blind Spot |
| O: Outdoor | 2: 2D |
| S: Static | 3: 3D |
| D: Dynamic | 200: CR=200 |
| NB: No Blind Spot | 50: CR=50 |

Table 3 can help us to symbolize and to give each case of our sixteen cases its own abbreviation. For instances: OD3-200 means Outdoor-Dynamic-3D with maximum 200 connection rate, and IS2-50 means Indoor-Static-2D with maximum 50 connection rate.

#### 5.2.1 Bandwidth utilization

In this subsection, we study BWU in more details under all cases by fixing two metrics each time, then comparing and deducing effects of these metrics on BW. Figure 3(a) shows that network utilize BW more efficiently at most cases when not considering existence of BS by 1.2% on average. Also, Figure 3(a) shows that 2D structure is more negatively affected by existence of BS; this is due to having small network space. Hence, connections in 2D have higher opportunity to fall down in BS than connections in 3D. Also, as shown in Figure 3(b) network more utilizes BW definitely when using Dynamic mechanism instead of Static one, the difference equal 7% on average. Moreover, Figure 3(b) reveals that a Dynamic borrowing mechanism is the suitable technique for busy networks. Figure 3(c) shows an unexpected result which is 2D space is more efficient than 3D space by 1.3%. In contrary to previous study (Al-Sharaeh, et al., 2008) which showed that 3D is more efficient due to increase of size of cell. But our explanation emphasizes our simulation results. The explanation is: Figure 3(c) shows that 3D structure on average is less by 3.5% comparing with 2D, This is because each round in simulator will be finished only when reaching the desired CR which is equal to 50 C/Round or equal to 200 C/Round, and due to having same number of connections distributed over 21 cells rather than 7 cells, which means that each cell portion from connections is less. Also, as Equation 4 presents, the used BW for each cell depends entirely on numbers of connections it has. Therefore, the outcome of BW utilization for 50 connections will be the same whether the structure is 2D or 3D, (See Equations 5 and 6), since the number of connections is fixed in 2D and 3D, and the number of cells in 3D is more than it in 2D. Also, the whole network bandwidth in 3D is more than that in 2D, so the denominator in 3D case is always larger than in 2D. Accordingly, the fraction (BWU) will be less for 3D.

$$uBW(C) = uBW\_nw(C) + uBW\_h(C) \quad (4)$$
$$TuBW += uBW(C) \quad (5)$$
$$BWuti = TuBW / (Cs * CBW) \quad (6)$$

Where: $1 \leq C \leq$ number of cells,
uBW(C) : used BW for a cell,
uBW_nw (C) : BW used by new connections for cell C,
uBW_h(C) : BW used by handoff connections for cell C,
TuBW : Total used BW,
BWuti : BW utilization,
Cs : number of cells,
CBW : cell BW.

Figure 3(d) depicts the difference of BWU when using variant network loads. As we can see, network with heavy load has more efficient BWU since it is busier than low loaded network, and due to having more connection to be served. The simulation showed that having 200 CR is better by

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2.7% than having 50 CR. Table 4 presents the difference between Indoor and Outdoor environments. The difference in BWU between them is very low which equals 0.2% in favor of Outdoor on average. Difference between Indoor and Outdoor appears clearly in D3B50 case.

*Table 4: Difference between Indoor and Outdoor for BWU*

| Study Case | BWU/ Indoor | BWU/ Outdoor | Diff. | in favor of |
|---|---|---|---|---|
| S2NB50 | 0.91130 | 0.91134 | 0.00345 | O |
| S2B50 | 0.87278 | 0.87919 | 0.72816 | O |
| S3NB50 | 0.87590 | 0.87540 | 0.05773 | I |
| S3B50 | 0.87562 | 0.87509 | 0.06066 | I |
| D2NB50 | 0.97651 | 0.97548 | 0.10486 | I |
| D2B50 | 0.96405 | 0.96586 | 0.18812 | O |
| D3NB50 | 0.94186 | 0.94180 | 0.00626 | I |
| D3B50 | 0.92422 | 0.94228 | 1.91610 | O |
| S2NB200 | 0.92283 | 0.92256 | 0.02963 | I |
| S2B200 | 0.88917 | 0.89322 | 0.45272 | O |
| S3NB200 | 0.91356 | 0.91351 | 0.00549 | I |
| S3B200 | 0.91344 | 0.91318 | 0.02932 | I |
| D2NB200 | 0.98899 | 0.98872 | 0.02771 | I |
| D2B200 | 0.98362 | 0.98437 | 0.07538 | O |
| D3NB200 | 0.98062 | 0.98062 | 0.00031 | O |
| D3B200 | 0.97464 | 0.98071 | 0.61904 | O |
| Avg. | 0.93182 | 0.93396 | 0.20% | O |

### 5.2.2 Connection blocking probabilities

In this subsection, we focus on CBP. Table 5 shows the difference in CBP when considering existence or absence of BS. The simulation showed that absence of BS is better by 1% than existence of BS on average. Table 4.5 (a) indicates that network with no BS and with Static mechanism has less CBP by 0.85% comparing with similar network, but with existence of BS, while Table 4.5 (b) shows that using Dynamic mechanism will improve performance (mentioned previously) by decreasing CBP by 9.99%.

*Table 5: Difference between nBS and wBS for CBP*

*Table 5 (a): Static schemes*

| Study Case | CBP/ No BS | CBP/ with BS | Diff. | % | in favor of |
|---|---|---|---|---|---|
| IS2-50 | 0.23400 | 0.23500 | 0.42553 | 0.43 | B |
| IS3-50 | 0.17200 | 0.16972 | 1.32781 | 1.33 | NB |
| OS2-50 | 0.23029 | 0.23681 | 2.75559 | 2.76 | B |
| OS3-50 | 0.16502 | 0.17145 | 3.74747 | 3.75 | B |
| IS2-200 | 0.26697 | 0.26730 | 0.12590 | 0.13 | B |
| IS3-200 | 0.23700 | 0.23585 | 0.48392 | 0.48 | B |
| OS2-200 | 0.25950 | 0.26093 | 0.54505 | 0.55 | B |
| OS3-200 | 0.23359 | 0.23679 | 1.35149 | 1.35 | B |
| Avg. | 0.22480 | 0.22673 | 0.85343 | 0.85 | B |

*Table 5 (a): Dynamic schemes*

| Study Case | CBP/ nBS | CBP/ wBS | Diff. | % | in favor of |
|---|---|---|---|---|---|
| ID2-50 | 0.14735 | 0.17819 | 17.30449 | 17.30 | B |
| ID3-50 | 0.07791 | 0.11729 | 33.57433 | 33.57 | B |
| OD2-50 | 0.14828 | 0.17608 | 15.78911 | 15.79 | B |
| OD3-50 | 0.07891 | 0.08106 | 2.64742 | 2.65 | B |
| ID2-200 | 0.21305 | 0.22493 | 5.27989 | 5.28 | B |
| ID3-200 | 0.18206 | 0.19834 | 8.20926 | 8.21 | B |
| OD2-200 | 0.21484 | 0.22391 | 4.05295 | 4.05 | B |
| OD3-200 | 0.18281 | 0.18363 | 0.44600 | 0.45 | B |
| Avg. | 0.15565 | 0.17293 | 9.99110 | 9.99 | B |

Table 6 presents the difference in CBP between Indoor and Outdoor, as we can see, Indoor has more probability to blocking connections than Outdoor, this probability equals 1.29% on average when using Static mechanism, and equals 3.7% when using Dynamic one.

*Table 6: Difference between Indoor and Outdoor for CBP*

*Table 6 (a): Static schemes*

| Study Case | CBP/ Indoor | CBP/ Outdoor | Diff. | % | in favor of |
|---|---|---|---|---|---|
| S2NB 50 | 0.234 | 0.23029 | 1.58675 | 1.59 | I |
| S2B 50 | 0.235 | 0.23681 | 0.7654 | 0.77 | O |
| S3NB 50 | 0.172 | 0.16502 | 4.05698 | 4.06 | I |
| S3B 50 | 0.16972 | 0.17145 | 1.0095 | 1.01 | O |
| S2NB 200 | 0.26697 | 0.2595 | 2.79551 | 2.80 | I |
| S2B 200 | 0.2673 | 0.26093 | 2.38585 | 2.39 | I |
| S3NB 200 | 0.237 | 0.23359 | 1.4384 | 1.44 | I |
| S3B 200 | 0.23585 | 0.23679 | 0.39617 | 0.40 | O |
| Avg. | 0.22723 | 0.224298 | 1.29054 | 1.29 | I |

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*Table 6 (b): Dynamic schemes*

| Study Case | CBP/ Indoor | CBP/ Outdoor | Diff. | % | in favor of |
|---|---|---|---|---|---|
| D2NB 50 | 0.14735 | 0.14828 | 0.62384 | 0.62 | O |
| D2B 50 | 0.17819 | 0.17608 | 1.18304 | 1.18 | I |
| D3NB 50 | 0.07791 | 0.07891 | 1.26974 | 1.27 | O |
| D3B 50 | 0.11729 | 0.08106 | 30.89043 | 30.89 | I |
| D2NB 200 | 0.21305 | 0.21484 | 0.82994 | 0.83 | O |
| D2B 200 | 0.22493 | 0.22391 | 0.45259 | 0.45 | I |
| D3NB 200 | 0.18206 | 0.18281 | 0.41463 | 0.41 | O |
| D3B 200 | 0.19834 | 0.18363 | 7.41415 | 7.41 | I |
| Avg. | 0.16739 | 0.16119 | 3.70392 | 3.70 | I |

We can see the outperforming of Dynamic mechanism over Static one on reducing the probability of blocking connections, where Dynamic has less probability by 6%, this is due to reserving a pool of BW for handoff connections by Static schemes. Also, 2D space is subjected to have more CBP than 3D by 4.9% on average. On the other hand, 6.2% is the difference between high CR and moderate CR.

**5.2.3 Connection dropping probabilities**

Here, simulation results show that WSN without BS has fewer probabilities for connection dropping, where the difference percentage between nBS and wBS is 0.23% for Static schemes and 3.25% for Dynamic schemes (See Table 7 for more details).

*Table 7: Difference between nBS and wBS for CDP*

*Table 7 (a): Static schemes*

| Study Case | CDP/ No BS | CDP/ With BS | Diff. | % | in favor of |
|---|---|---|---|---|---|
| IS2-50 | 0.25241 | 0.25454 | 0.83649 | 0.84 | B |
| IS3-50 | 0.21622 | 0.21644 | 0.10165 | 0.10 | B |
| OS2-50 | 0.25382 | 0.25469 | 0.34506 | 0.35 | B |
| OS3-50 | 0.21700 | 0.21736 | 0.1653 | 0.17 | B |
| IS2-200 | 0.26697 | 0.2673 | 0.1259 | 0.13 | B |
| IS3-200 | 0.25478 | 0.25457 | 0.08305 | 0.08 | NB |
| OS2-200 | 0.26665 | 0.26827 | 0.60256 | 0.60 | B |
| OS3-200 | 0.25500 | 0.25434 | 0.25833 | 0.26 | NB |
| Avg. | 0.247856 | 0.248439 | 0.23446 | 0.23 | B |

*Table 7 (b): Dynamic schemes*

| Study Case | CDP/ nBS | CDP/ wBS | Diff. | % | in favor of |
|---|---|---|---|---|---|
| ID2-50 | 0.19397 | 0.20548 | 5.60301 | 5.60 | B |
| ID3-50 | 0.08367 | 0.11948 | 29.97631 | 29.98 | B |
| OD2-50 | 0.19209 | 0.20339 | 5.55577 | 5.56 | B |
| OD3-50 | 0.08341 | 0.086 | 3.01963 | 3.02 | B |
| ID2-200 | 0.27723 | 0.26483 | 4.47284 | 4.47 | NB |
| ID3-200 | 0.19449 | 0.20727 | 6.16596 | 6.17 | B |
| OD2-200 | 0.27888 | 0.26554 | 4.78419 | 4.78 | NB |
| OD3-200 | 0.19444 | 0.19651 | 1.05391 | 1.05 | B |
| Avg. | 0.187273 | 0.193563 | 3.24960 | 3.25 | B |

Table 8 shows that dropping probability for Outdoor is more than Indoor by 0.2% on average for Static schemes (See Table 8 (a)), while Indoor network with Dynamic schemes achieves 2.99% increasing in CDP, as shown in Table 8 (b).

*Table 8: Difference between Indoor and Outdoor for CDP*

*Table 8 (a): Static schemes*

| Study Case | CDP/ Indoor | CDP/ Outdoor | Diff. | % | in favor of |
|---|---|---|---|---|---|
| S2NB 50 | 0.25241 | 0.25382 | 0.55442 | 0.55 | O |
| S2B 50 | 0.25454 | 0.25469 | 0.06159 | 0.06 | O |
| S3NB 50 | 0.21622 | 0.217 | 0.36142 | 0.36 | O |
| S3B 50 | 0.21644 | 0.21736 | 0.4249 | 0.42 | O |
| S2NB 200 | 0.26697 | 0.26665 | 0.11877 | 0.12 | I |
| S2B 200 | 0.2673 | 0.26827 | 0.35892 | 0.36 | O |
| S3NB 200 | 0.25478 | 0.255 | 0.08749 | 0.09 | O |
| S3B 200 | 0.25457 | 0.25434 | 0.08801 | 0.09 | I |
| Avg. | 0.247904 | 0.248391 | 0.19626 | 0.20 | O |

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*Table 8 (b): Dynamic schemes*

| Study Case | CDP/ Indoor | CDP/ Outdoor | Diff. | % | in favor of |
|---|---|---|---|---|---|
| D2NB 50 | 0.19397 | 0.19209 | 0.96615 | 0.97 | I |
| D2B 50 | 0.20548 | 0.20339 | 1.01568 | 1.02 | I |
| D3NB 50 | 0.08367 | 0.08341 | 0.30837 | 0.31 | I |
| D3B 50 | 0.11948 | 0.086 | 28.01868 | 28.02 | I |
| D2NB 200 | 0.27723 | 0.27888 | 0.59094 | 0.59 | O |
| D2B 200 | 0.26483 | 0.26554 | 0.26588 | 0.27 | O |
| D3NB 200 | 0.19449 | 0.19444 | 0.02674 | 0.03 | I |
| D3B 200 | 0.20727 | 0.19651 | 5.19185 | 5.19 | I |
| Avg. | 0.193303 | 0.187533 | 2.98495 | 2.99 | I |

Dynamic mechanism is more efficient in CDP resistance especially in 3D cases. Dynamic has less CDP than Static by 5.8% on average. Also, the difference in CDP between network with 200 CR and network with 50 CR is 5.7% on average.

### 5.2.4 Variant Lambda effects

To show the effect of Lambda, we ran simulation for different values of Lambda. Simulator showed that when Lambda ranges between (5 to 7.5), the BWU is in its highest utilization. Lambda equals the number of shares that can be borrowed from one connection, since Lambda and value of one share are contrary. If we have large lambda, then the share becomes small. So when a base station has no enough BW, and borrows from current connections, this borrowing needs a lot of shares to achieve the minimum BW for one connection, which is not efficient. In contrary, if we have small Lambda and large share (with one share value is larger than minimum BW), then borrowing one share from a connection will degrade QoS in lender connection, Moreover, borrower connection will have more than its minimum BW and this is not effective and not fair beside being useless in BWU.

### 5.2.5 Variant fair factor effects

Due to the fact that fair factor $f$ will determine borrowed BW for cells, so if $f$ is small, then the amount of BW will be small, and as a result having higher connections rate means more blocking and dropping, which yields less BWU, simulator shows that the best value for $f$ is 1, which means that the connection tolerates with the maximum difference BW (between maximum and minimum) to be borrowed. Also, we can conclude that suitable value for $f$ is one, and this is congruous with (Al-Sharaeh, et al.,2008).

### 5.2.6 Variant Blind Spot Effects

Blind spot is an important factor in QoS, because large BS means high probability for connection to be originated or to move into this spot. Therefore, there is a direct proportion between the size of BS and non-admission of connections.

## 6. CONCLUSIONS AND FUTURE WORKS

In this study, we have proposed a new scheme (A3D-DBBS) where we aim to find: best structure, space, and mechanism for WSNs to have high QoS guarantees. Having a WSN with high guarantees requires three conditions: achieving high BWU, and at same time decreasing CBP and CDP. To achieve this goal, we considered sixteen different study cases, by applying two borrowing mechanisms (Static and Dynamic). We can conclude, based on simulation results, that using Dynamic borrowing mechanism is better than using Static one. Also, 3D is more suitable when thinking of QoS. And existence of BS will decrease the QoS that network can warrant. Finally, when looking for better QoS in general, network with connection rate up to 50 is more preferred than the one with 200 CR. In this study, we constrained on homogenous sensors in network. So, we suggest studying heterogeneous WSNs. We also considered the radius as the only different factor between Indoor and Outdoor cases, while it is more realistic to consider BER as another factor which yields from RF interference in Indoor environment.

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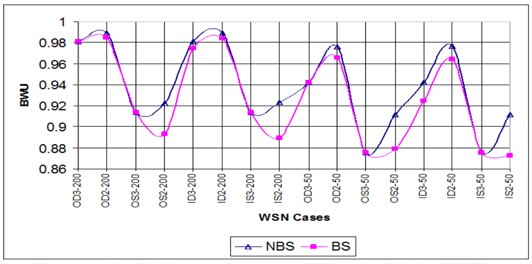


**Figure 3(a): Difference between nBS and wBS for BWU**

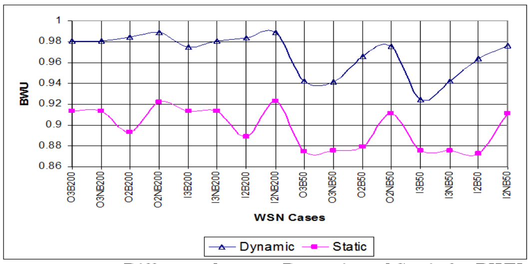


**Figure 3(b): Difference between Dynamic and Static for BWU**

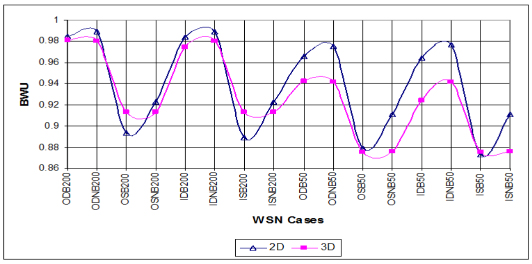


**Figure 3(c): Difference between 2D and 3D for BWU**

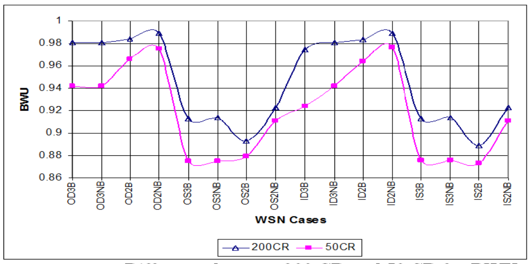


**Figure 3(d): Difference between 200 CR and 50 CR for BWU**

*Figure 3: Bandwidth Utilization (BWU)*

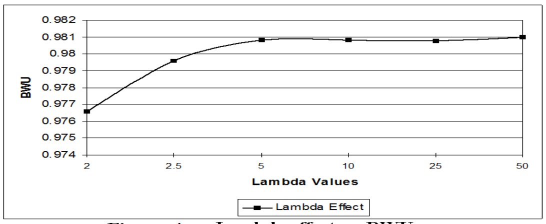


**Figure 4(a): Lambda effect on BWU**

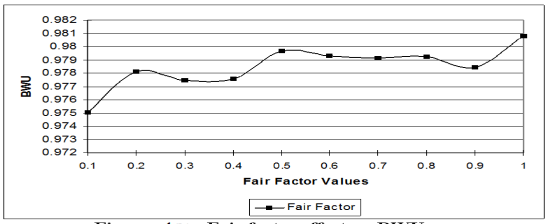


**Figure 4(b): Fair factor effect on BWU**

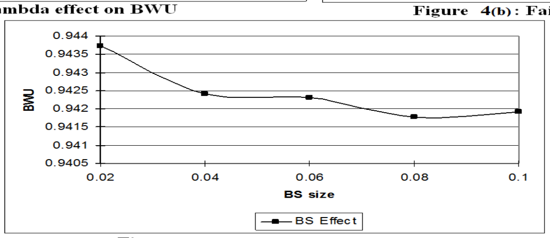


**Figure 4(c): BS size effect on BWU**

*Figure 4: Variant Effects on Bandwidth (BWU)*