Experimental Analysis for Optimal Separation between Sensor and Base Station in WBANs

Zuneera Aziz*, Umair Mujtaba Qureshi*, Faisal Karim Shaikh*†, Nafeesa Bohra*, Abdelmajid Khelil‡, Emad Felemban†
*Department of Telecommunication Engg., Mehran UET, Jamshoro, Pakistan.
Email: {zunera.aziz|umair.mujtaba|nafeesa.zaki}@tl.muet.edu.pk
†STU, Umm Al-Qura University, Makkah, Saudi Arabia.
Email: {fkshaikh|eafelemban}@uqu.edu.sa
‡TU Darmstadt, Germany.
Email: abdelmajid.khelil@ieee.org

***Abstract*—The reliable delivery of data is important in designing Wireless Body Area Networks (WBANs) employed for critical applications such as e-health. In order to communicate the data reliably from the sensors to the base station, the data transmission technique (star or multi-hop) and the transmission power plays a very important role. As transmission power is increased, transmission distance is increased and the data can be sent reliably to far nodes. However, in WBANs, there is always a limit to increase the transmission power. Keeping the power level at some low threshold and increasing the distance between a sensor and the base station results in reduced received power which ultimately degrades the data transmission. Thus, for star data transmission technique, the point to ponder is the maximum separation between a sensor and the base station to transmit the data reliably. The reliability in WBANs can be analyzed through different parameters such as received power, received signal strength indicator, link quality indicator, packet error rate, packet reception rate, etc. This paper aims at performing a reliability analysis for WBAN through the mentioned parameters to suggest an optimal sensor/base station separation using star data transmission technique. This analysis is performed employing the default routing protocol in TinyOS called the Collection Tree Protocol. Our study considers different sensor placements on different parts of the body as well as different angular offsets between sensor and base station.**

I. Introduction

The rising cost of medical procedures and monitoring patients have led to the design of miniaturized wearable and communicating sensors which can be deployed over the human body. These sensors form a wireless network called as Wireless Body Area Network (WBAN) which can communicate with the outside world or the respective entity through a base station [1]. This accounts for intelligent networks consisting of wearable sensors to enable promising applications. These networks have been further exploited to cater other applications such as applications related to lifestyle and sports [2]. As a modern trend, smart phones are being equipped with sensors to deal with health-care and other WBAN applications.

In WBAN generally the sensors are deployed on human body in order to collect data about the vital signs such as heart rate, blood pressure, Electrocardiography (ECG), and temperature and route the data to the base station as shown in Fig. 1. The base station sends the collected data to the Medical Health Service (MHS) through WiFi or a third party carrier using 3G/4G. The doctor can analyze the data and instruct the patient accordingly using the MHS. However, an on-going research area is the usage of actuators [3] where the data can also be sent to the device from the doctor that has to start taking the action (e.g., insulin as an actuator).

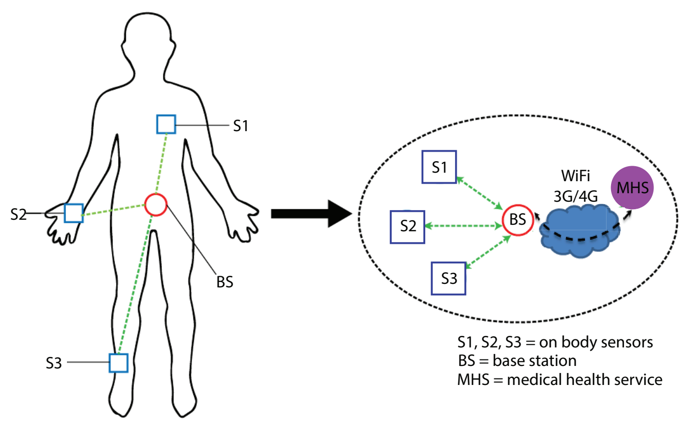

Fig. 1. General scenario of data transmission in WBANs

Generally, the WBAN applications related to health-care are very crucial [4]. For instance during a catastrophic condition such as earthquake a reliable data transfer of vital signs from WBAN to the respective MHS is required. Similarly, if a patient require continuous cardiac monitoring and in a worst case scenario requires an immediate medical attention, the unreliable communication may result in loss of precious life of a patient. Therefore, the network architecture and data transmission techniques play a vital role in assessing the reliability of WBAN.

The reliability in WBANs highly depends on the data transmission protocols, the distance between the sensors and the base station as well as the transmission power [5]. This paper analyzes the reliability of data transmission based on Received Signal Strength Indicator (RSSI), Packet Error Rate (PER), Packet Reception Ratio (PRR), Link Quality Indicator (LQI). The analysis suggests an optimal placement of sensors

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which ultimately leads to the optimal separation between the sensors and the base station. This work also considers the placement of sensors in WBAN with respect to different body postures (i.e., different angular offsets between the sensors).

The rest of the paper is formulated as follows. Section II gives an overview of the related work. Section III explains the reliability assessment framework. Section IV gives an experimental evaluation on the basis of the framework. Finally, Section V concludes the paper and outlines future directions.

II. Related Work

The reliability in WBANs has been one of the key factors in designing e-health applications. Different researchers have selected various protocols, data transmission techniques and reliability parameters for analyzing WBANs performance. Also, most of the research on WBANs have been confined to analyzing the sensed data [6] without analyzing the data transmission technique and network architecture. This leads to intense signal processing so that meaningful results are obtained. However, a few authors have worked on analyzing the reliability with respect to certain parameters such as packet loss, latency, and PRR [7], [8], [9].

In [10], the authors suggest that reliability and energy efficiency of WBANs can realize optimal performance for e-health applications. The authors further suggest that for reliability, network architecture plays a key role. The parameters selected in that work are PRR, collection delay, energy consumption and energy balancing and these parameters have been tested with star and multi-hop data transmission techniques. The sensors are programmed with Collection Tree Protocol (CTP). However, other parameters such as RSSI, received power, LQI and PER have not been analyzed. Furthermore, the impact of movement of body parts is also not considered.

In [8] the authors have suggested that reliability and energy efficiency play a crucial role in designing WBANs for e-health applications. The authors have developed a low-overhead Energy Efficient Routing Scheme (EERS) by combining routing strategies and adaptive power control as a performance metric. Later, CTP and EERS are compared for reliability using PRR, collection delay, energy consumption and energy balancing as the parameters based on multi-hop data transmission technique. However, star techniques have not been taken into consideration to suggest optimal separation between sensor and base station.

The authors in [9] have investigated the performance of WBANs with RSSI and PRR. Irrespective of the routing protocol, the authors have carried out experiments in different environments to observe the RSSI and have concluded that RSSI changes significantly with minor postural or environmental changes and that less number of samples cannot be taken as an estimation to evaluate the performance.

The existing literature lacks in finding an optimal sensor - base station separation based on reliability parameter analysis when the data transmission technique under consideration is Star. Therefore, this work aims to perform a reliability analysis through CTP (default routing protocol in TinyOS), based on RSSI, LQI, PER, PRR and received power, to suggest an optimal sensor - base station separation.

III. Assessment Framework

In order to find the optimal sensor-base station separation we first describe the performance metrics used for the evaluation. Next we describe our methodology and settings and classify the deployment scenarios which covers the basic WBAN strategies for data transmission.

A. Performance Metrics

Many parameters such as packet loss, latency, single point failure recoveries, probability of success, etc. [11] exist to analyze the reliability of WBAN. Our reliability analysis is based on following short listed parameters which are readily available in TinyOS, i.e., RSSI, received power, PRR, LQI and PER.

- **Received Signal Strength Indicator (RSSI)**:
  The RSSI is the measurement of the power present in the radio signal. The values are arbitrary and depend on the entity used. The least value for AT86RF230 [12] Radio Frequency (RF) module employed in Iris motes is 0. The highest value is 28. Eq.(1) translates the RSSI to power values [12].

  $$P_{RF} = RSSI_{base} + 3(RSSI - 1) \tag{1}$$

  where, P_{RF} is the power in the received radio frequency and $RSSI_{base}$ is the minimum RSSI sensitivity in AT86RF230 module, which is -91 dBm. The raw RSSI values which are readily available are then converted to power values since RSSI and power are inter-related.
- **Packet Reception Ratio (PRR)**:
  PRR quantifies the ratio of the received packets to the transmitted packets. The maximum value being 1 and the minimum value is 0. A maximum value of 1 is an ideal value which means that all the packets that have been transmitted were received successfully. PRR is given as:

  $$PRR = \frac{PacketsReceived}{PacketsTransmitted} \tag{2}$$
- **Link Quality Indicator (LQI)**
  LQI is a link quality indicator. It depicts how strong the communication link is between two nodes in a network. For AT86RF230 [12], the highest LQI value is 255 which indicates stronger connectivity. Whereas, the lowest value is 0 which indicates a weak connectivity.
- **Packet Error Rate (PER)**
  PER reflects the number of packets in error from the received packets. The PER highly depends on the LQI.

B. Methodology and Settings

To create a WBAN in a realistic environment we selected commercially available Crossbow Iris [13] motes (Table I).

The base station was connected to a computer to coordinate the experimental evaluation. At the start of the experiment the

TABLE I
IRIS MOTE TECHNICAL SPECIFICATIONS

Parameters	Values
Default Power (raw value)	0
Default Power (dBm)	3
Default Power (Watts)	1.99m
Default Channel	11
Upper Cut-off Frequency (GHz)	2.405
Lower Cut-off Frequency (GHz)	2.41

nodes on the body start scheduled transmission to the base station. The sensor node senses the reading and route it to the base station through tree construction with CTP. Since, we have used only one sensor and one base station, therefore the packet is directly sent. Each node sends 300 packets with an interval of 1 sec at the lowest transmit power. The Iris mote have least transmit power to be approximately 19.95μW (-17dBm) which gives a minimum range of approximately 5m. For WBANs the ideal transmit power is around 4μW in order to avoid any health hazards related with it and to achieve the transmission rage suitable for the length human body. Accordingly, the nodes are provided with a calculated amount of attenuation to limit the transmit power to as low as 4μW by wrapping the dipole antenna with aluminium foil as shown in Fig. 2. By having 4μW transmission power, a transmission rage of 1.5m is achievable.

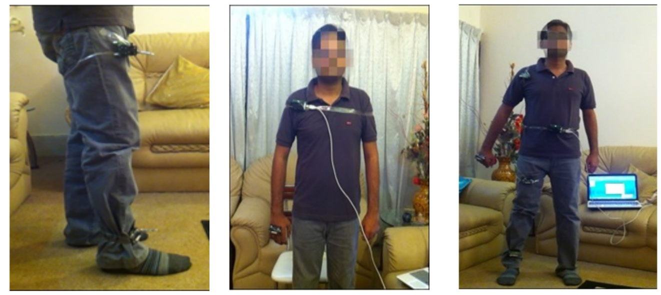
Fig. 2. Modifications to Iris motes to reduce transmission power

The analysis is performed through MViz (a network visualization tool) and MsgReader application in TinyOS [14]. The underlying routing protocol to send the packets was CTP [15] being the default protocol in TinyOS. The motes are then programmed with applications for calculating the parameters such as RSSI, PRR, PER and LQI.

C. Deployment Scenarios

Three cases with respect to sensor positions on the human body were taken into consideration.

1) Case I: Deployment of Sensor on Leg: The sensor and base station are, at maximum, separated by a distance of 24 inch (2 ft) on the leg. The RSSI, PRR, PER and LQI measurements are taken individually at distances 2 inch to 24 inch with a step-size of 2 inch between the sensor and base station. The deployment arrangement of sensors is shown in Fig. 3(a).



(a) Case I (b) Case II (c) Case III

Fig. 3. Deployment scenarios for the experiments

Furthermore, different angular offsets as shown in Fig. 4 are analyzed for the senor deployed on the leg. These offsets generally cover all the movements of the leg, i.e., walking, running, sitting etc.

(a) 0^o (b) 45^o (c) 90^o

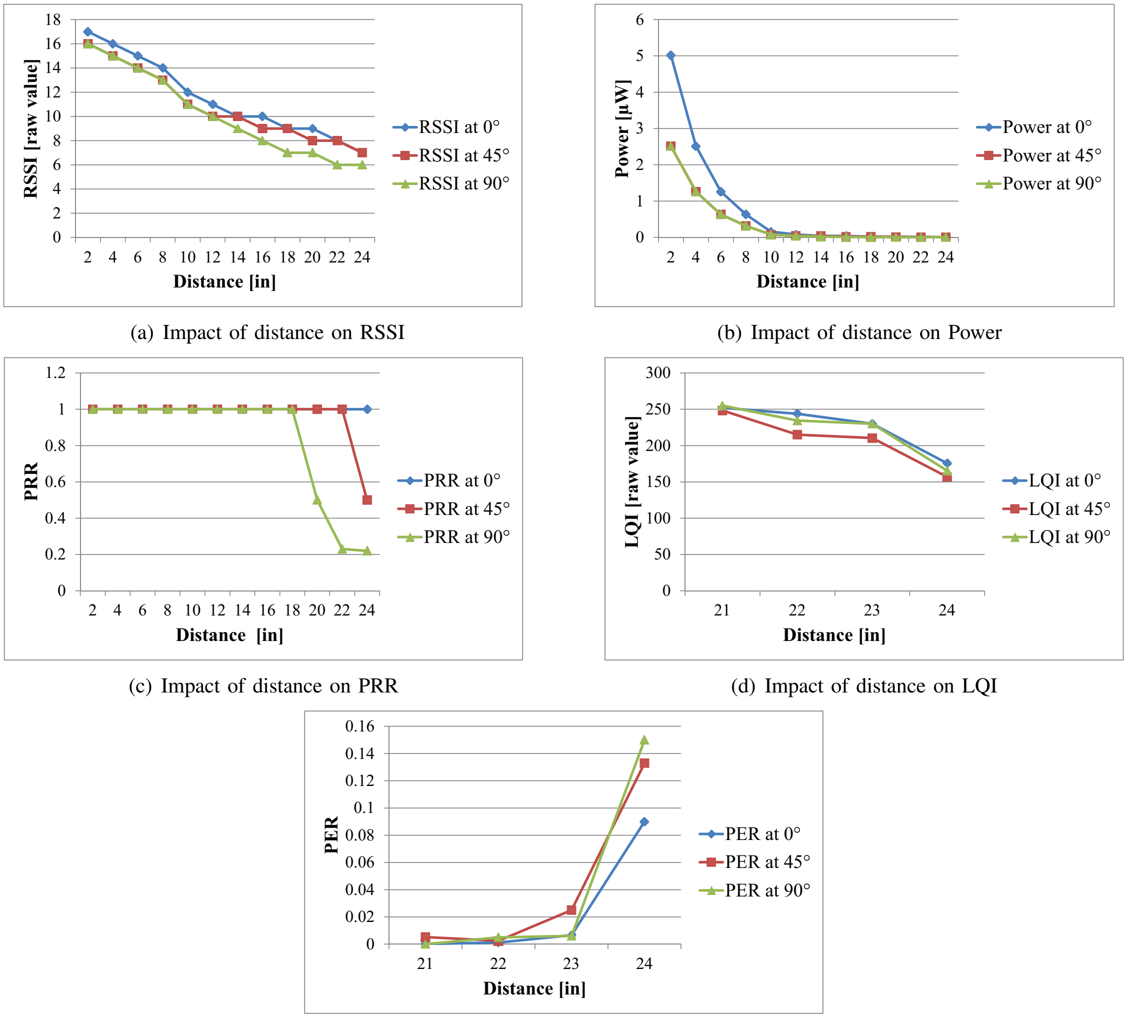
Fig. 4. Angular offset between sensor and base station for Case I

(a) 0^o (b) 45^o (c) 90^o

Fig. 5. Angular offset between sensor and base station for Case II

2) Case II: Deployment of Sensor on Arm: In this case, the sensor node is deployed on the arm as shown in Fig. 3(b). Also, in this scenario the sensor and the base station are, at maximum, separated by a distance of 24 inch (2 ft). The RSSI, PRR, PER and LQI measurements are taken individually at distances of 2 inch to 24 inch with a step-size of 2 inch between the sensor and the base station. The angular offsets of 0^0, 45^0, and 90^0 between sensor and base station are analyzed as shown in Fig. 5. These angular offset cover almost all arm movements.

3) Case III: Activation of Case I and Case II simultaneously: The full activation of Case I and Case II simultaneously consists of deployment of 1 sensor on the leg, 1 on the arm,



(a) Impact of distance on RSSI

(b) Impact of distance on Power

(c) Impact of distance on PRR

(d) Impact of distance on LQI

(e) Impact of distance on PER

Fig. 6. Results of Case I: Angular offset between sensor and base station on leg

base station on abdomen and two intermediate motes, one on thigh and one on shoulder respectively. This arrangement is shown in Fig. 3(c).

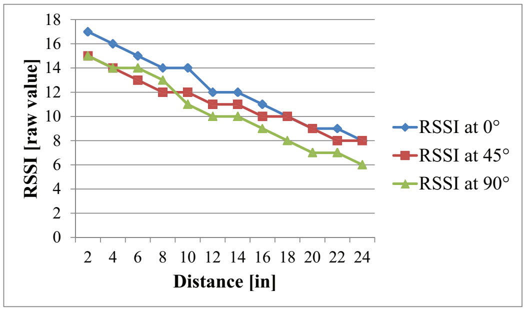
IV. Experimental Evaluation

It was analyzed from the experiments that an RSSI of 8 or greater would result in a PRR of 0.90 or higher. However, even if the PRR is greater than 0.90, the PER value should be taken into consideration as packets may all be received but in error. The maximum separation is suggested on the basis of a PRR > 0.90 and a PER < 0.05.

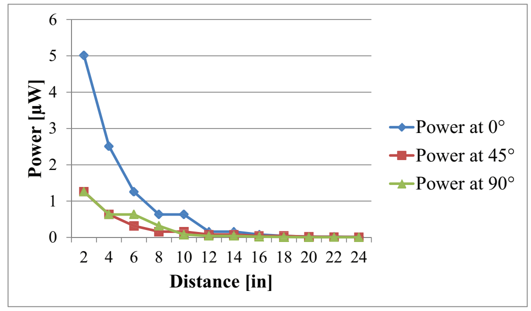
For Case I, the results have been analyzed for angular offsets of 0^o, 45^o and 90^o respectively between the sensor and the base station for various distances as shown in Fig. 6. It is observed from Fig. 6(b) that as distance increases, reception power is decreased. This reception power corresponds to different RSSI values as shown in Fig. 6(a). The LQI value can also be observed in Fig. 6(d). PRR and PER are the parameters that decide how many packets have been received and how many packets are in error. It is clearly seen in Fig. 6(c) that PRR is optimum upto 22 inch in Case I at 0^o. However, at 24 inch, although packets are received but most of the packets are in error as shown in Fig. 6(e). At 45^o angular offset, the distance is restricted to nearly 20 inch because PRR is decreased after the specified distance. At 90^o angular offset, the optimal separation is almost 16 inch.

For Case II, the results are depicted in Fig. 7. It can be seen in Fig. 7(a) that RSSI is degraded after 8 inch but still a good PRR is maintained up to 17 inch (for 90^o offset) as shown in Fig. 7(c). At 0^o, RSSI of at least 8 is maintained up to 24 inch along with a good PRR (>0.90). However, PER increases (>0.05) with the increase in distance. Therefore, a maximum separation of almost 23 inch is optimum at 0^o. At 45^o, the PRR is decreased (<0.90) after 22.5 inch. Therefore, a separation of nearly 22 inch is suggested to maintain a good PRR (>0.90) and PER (<0.05). At 90^o, a separation of nearly 17 inch is suggested.

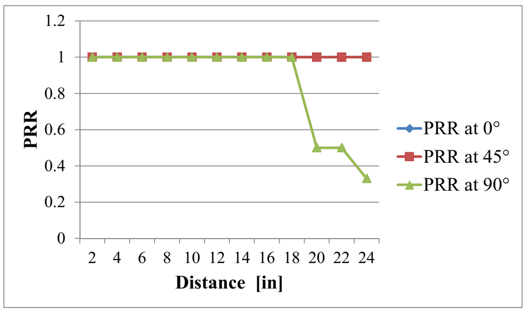
In Case III, the results were analyzed by activating Case I and Case II simultaneously. The results are shown in Fig. 8. The results show that if simultaneously sensors are deployed



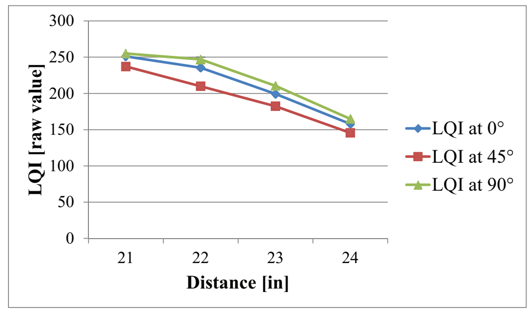
(a) Impact of distance on RSSI



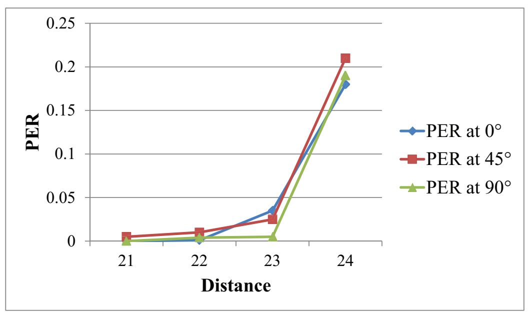
(b) Impact of distance on Power



(c) Impact of distance on PRR

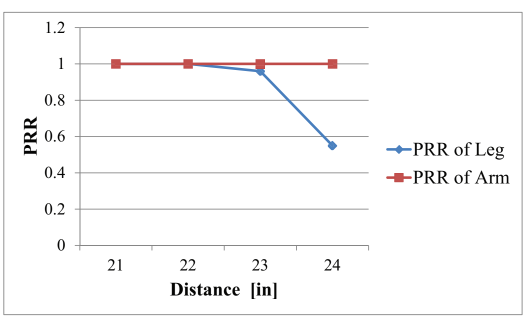


(d) Impact of distance on LQI

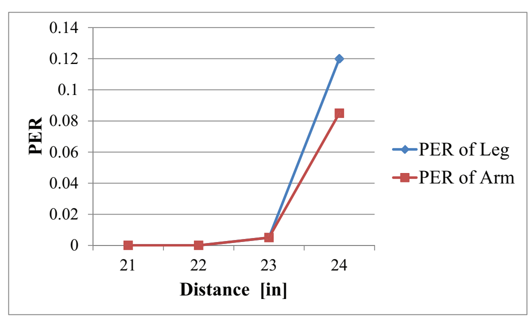


(e) Impact of distance on PER

Fig. 7. Results of Case II: Angular offset between sensor and base station on arm



(a) Impact of distance on PRR



(b) Impact of distance on PER

Fig. 8. Results of Case III: Activation of Case I and Case II simultaneously

on Arm and Leg then PRR is decreased after 22 inch and PER is increased after 22 inch. This clearly shows that optimal separation is nearly 22 inch. These results have been taken at angular offset of 0^o only.

The overall results are summarized in Table II. These results can be achieved in different body postures such as standing, sitting and walking. Worst case scenario arises when a person is sitting or standing with bent knees or arms (corresponding to 90^o offset). In such situations, the distance between sensor and base station would be lower compared to a standing and stretched arms positions (corresponding to 0^o offset). Moreover, if a person bends knees or arms partially

TABLE II
OPTIMAL SEPARATION BETWEEN SENSOR AND BASE STATION AT DIFFERENT ANGULAR DISPLACEMENTS

Case	0 Degree	45 Degree	90 Degree
I	$22''$	$20''$	$16''$
II	$23''$	$22''$	$17''$
III	$22''$	-	-

(corresponding to 45^o offset), the separation is restricted to 20 inch and 22 inch for sensor placement on arm and leg respectively.

Based on the presented results we propose a maximum separation of 16 inch between the sensor and the base station to achieve a reliable communication. The results also highlight the fact that the angular offsets reduce the separation by nearly 4 inch. The effect happens due to the radiation pattern of the dipole antenna, which reduces the radiated power at 45^o and 90^o respectively.

V. Conclusion and Future Work

In this paper, we analyzed the optimal placement of sensor and base station on the basis of RSSI, PRR, LQI and PER for three different cases in real environment. These cases were based on different position of sensors on arm and leg to form a WBAN. These cases were further analyzed based on angular offsets of 0^o, 45^o and 90^o between sensor and base station. The results show a maximum of 16 inch separation between the sensor and base station guarantees a reliable communication between them. Furthermore, the results show that the angular offsets slightly effect the reliable communication.

For future, different routing protocols can also be analyzed with similar parameters. The work can also be extended for multi-hop data transmissions to increase the separation between the source sensor and the base station to achieve optimal performance in unusual scenarios and also to fit the height of the people.

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