Proceedings of 2010 IEEE Student Conference on Research and Development (SCOReD 2010),
13 - 14 Dec 2010, Putrajaya, Malaysia

Utilising MIMO for Location and Positioning in IMT-Advanced Systems

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Abstract – **With the advances of multiple input multiple output (MIMO) technology as one of IMT-Advanced features, it has become feasible to adopt the technology into the mobile location scenario. By exploiting the multipath characteristics of the MIMO system, it is possible to estimate the position of mobile stations (MS) by considering the capability of MIMO to mitigate the non line of sight (NLOS) conditions that deteriorate the accuracy of location estimation. In this paper we developed geometric approach by utilizing the advantages of MIMO system and employ the time of arrival (TOA) as range measurements for improving location estimation. The performance of the proposed method has been evaluated through computer simulation. The results of our simulation demonstrate that the proposed algorithm is significantly more effective in location accuracy than the conventional technique (LLS algorithm) and MIMO antenna configurations can achieve high accuracy for location estimation which meets the Federal Communications Commission (FCC) requirements.**

Index Terms- **MIMO, TOA, Location Estimation.**

I. INTRODUCTION

In recent years, location detection and positioning in wireless technology have attracted a huge interest and contribute a major benefit to both the society and the industry. By knowing a user's position, various applications such as tracking, location sensitive billing, public safety and enhanced emergency services, intelligent transportation systems (ITS), and etc [1] can be made possible. Due to high demand on unlimited services and applications, wireless broadband communications are becoming more popular since the users are provided with "anywhere and at any time" kind of service. With the existence of IMT-Advanced, the technology is able to fulfill the most important features of the next generation wireless systems. Indeed, IMT-Advanced have some unique features that can be employed for enhancing the positioning accuracy [2, 3] especially MIMO which can be applied for improving mobile location estimation accuracy.

Fundamentally, the MS position can be determined using various parameters such as signal strength (SS), angle of arrival (AOA), TOA, time difference of arrival (TDOA), hybrid methods, and etc [1, 4, 5]. The accuracy of mobile location schemes depends on the propagation conditions of wireless channels. If the line of sight (LOS) propagation exists between the MS and the all base stations (BSs), high location estimation accuracy can be achieved. Practically, however, due to multipath and NLOS problems of the wireless environments, precise estimation of these parameters at multiple BSs imposes greater challenges, which result in poor accuracy in the estimation of MS location, no matter which method is employed. Therefore, positioning with an NLOS can causes considerable degradation of mobile location accuracy. This has lead to the development of many location algorithms that concentrate on identifying and mitigating the NLOS error. The algorithm proposed in [6] uses signal measurements at a set of participating BSs and weighting techniques to mitigate NLOS effects. But if the propagations at all BSs are NLOS, this algorithm cannot improve the location accuracy. A new linear lines of position method (LLOP) presented in [7] has made the estimation of the unknown MS location easier than traditional geometrical approach of calculating the intersection of the circular lines of position (CLOP) [8]. LLOP algorithm can mitigate the NLOS error as well as the measurement noise. However, all the papers described above only consider the SISO antenna mode configuration. On the other hand, only a single of TOA measurement is considered between the BS and MS. With the advances in radio miniaturization and integration of MIMO technology; recently it has become feasible to adopt the technology into the mobile location scenario [9]. By exploiting the multipath characteristics of the MIMO system, it is possible to determine the position of MS by considering the capability of MIMO to mitigate the NLOS conditions.

Basically, there are two approaches that can be used in computing the estimation of a location: geometrical and statistical approach. In this paper, our focus will be the first approach by using parameter measurements of TOA for MIMO system by adopting the technique proposed in [7]. This method is based on the inherent geometrical relationship between the BS locations and the TOA measurements. The traditional geometric approach in determining the position of an MS is by solving the intersection of the CLOP. When NLOS errors are introduced into the TOA measurements, the CLOP will not intersect at a point. This has lead to more statistically justifiable methods such as linear least squares (LLS) [8, 10]. When approaching location estimation through the geometric point of view, solving this set of equations is cumbersome task which can be made simpler through a different interpretation of the location geometry. Therefore, instead of using CLOP for TOA location, a new geometry approach based on the LLOP method can be introduced along with the MIMO system in which it is capable to reduce the NLOS errors.

The remainder of this paper is organized as follows. In Section II, we present the system models used to perform the simulation results. The new geometrical algorithm based on

LLOP for MIMO system at three BSs has been proposed in Section III. Section IV discusses the performance of the proposed algorithm evaluated via computer simulations. Finally, our concluding remarks are given in section V.

II. IMT-ADVANCED SYSTEM MODEL

The IMT-Advanced model used is according to the IEEE802.16e standard, which is based on cellular system [11]. In this scenario, the model consists of minimum three synchronized WiMAX BS and a MS with capability of MIMO antenna mode as depicted in Fig. 1.

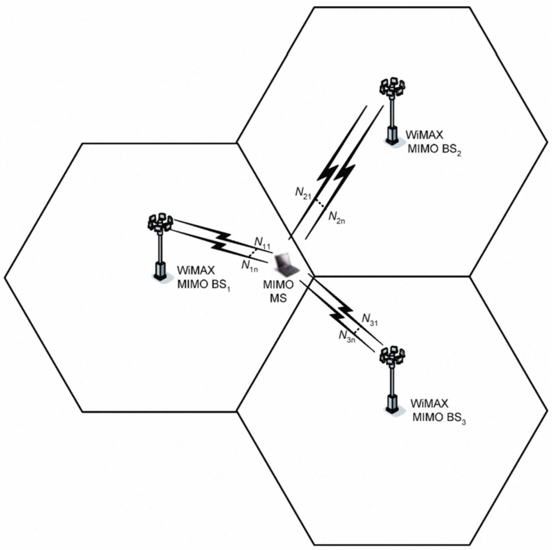

Fig. 1 WiMAX MIMO System Architecture

We consider the MIMO antenna is diversity antenna, so that only TOA measurements are taking into account. In the WiMAX downlink, there is a preamble consist of a known OFDM(A) symbol that can be used to attain initial synchronization between the BSs and the MS [11]. Therefore, under the assumption that transmitter and receiver are perfectly synchronized, the MS is able to identify the TOA signals from each MIMO antenna based on detection of downlink preamble signals that are transmitted by each WiMAX MIMO BS as shown in Fig. 2 which was obtained as a result of IMT-Advanced simulation. Furthermore, in MIMO-OFDM(A), the received signal at each antenna is a superposition of the signals transmitted from the N_t transmit antennas. Thus, the preambles for each transmit antenna need to be transmitted without interfering with each other. It is assumed that noise processes at different receiver antennas are independent and that there is sufficient separation between all antenna pairs so that different channel coefficients can be observed at different antennas. In addition of preamble signal used in determination of TOA, the location of WiMAX BSs must be known prior the calculation of positioning can be made. In the [11], WiMAX BSs broadcast periodically their location-based services (LBS) information to MSs via the LBS_ADV message. The LBS_ADV message shall include the BS's coordinate. Based on preamble signals and BS's coordinate, the MS position can be easily determined by using the proposed algorithm as explained in Section III.

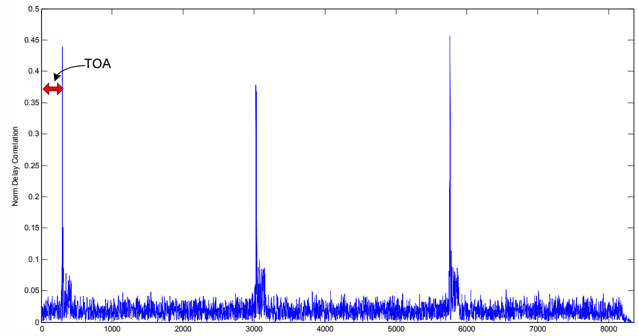

Fig. 2 TOA Detection Using Preamble Delay Correlation Conjugate Symmetry Search (SNR 10 dB)

III. GEOMETRY APPROACH OF NEW LLOP FOR MIMO SYSTEMS

In this approach, we extend the work done by J. J. Caffery, Jr. [7]. The paper only considers SISO antenna mode configuration where only one TOA measurement is taken into consideration from each BS, whereas we focus on MIMO antenna mode configurations where more TOA signals are used to estimate the location of MS as shown in Fig. 3. We consider the numbers of circles developed for each BS is proportional with the multiplication of number of transmitter antenna, N_t and number of receiver antenna, N_r. Fig. 3 illustrates an example of geometry of TOA based location for MIMO 2x1 when three BSs are involved and it can be extended for others MIMO antenna configurations.

Assuming a homogeneous propagation environment and the existence of the LOS, the propagation delay is related to the MS position according to the following equation

$$t_i = \frac{r_i}{c} \tag{1}$$

where

$$r_i = \sqrt{(x_i - x_u)^2 + (y_i - y_u)^2} \tag{2}$$

is the measurement range between the MS and the BS i, (x_i, y_i) is the coordinates of the BS i , (x_u, y_u) is the true MS position, t_i represents the TOA associated to the BS i and c is the speed of light. In the conventional trilateration method, using at least three BSs to resolve ambiguities, the MS's position for MIMO antenna configurations is given by the intersection of circles as shown in Fig. 3 (with the dotted straight lines ignored).

The approach presented here for calculating the intersection of the multiple circles is shown in Fig 3, where the dotted lined straight lines represent the LLOP and the circles are CLOP. Fig. 4 on the other hand shows the enlarged view of multiple LLOP that provide the possible few estimations of MS location from the intersection of the straight lines. According to Fig. 3, each pair of circles can intersect with at most two points which can be used to define a straight line. For instance, in the case of MIMO 2x1 there are four straight lines have been projected. The intersection of these lines provides the possible estimation of the MS location. Therefore, the lines define new lines of position namely Linear Lines of Position (LLOP). In order to determine the equations for the new LLOPs, we must start with the original circular LOP equations as given in equation (2) for $i = j,2,\ldots,N$, where N is the number of BS and $j = 1$. Consider BS_j as the serving cell and $j = 1$. The new line which passes through the intersection of the two circular of LOPs for those two BSs can be found by squaring and differentiating the ranges in (2). More specifically, firstly, we must calculate the range of each TOA signal from the serving cell, BS1.

$$r_{j,n} = \sqrt{\left(x_j - x_u\right)^2 + \left(y_j - y_u\right)^2} \tag{3}$$

for $j = 1$ and $n = 1,2,\ldots N_t \times N_r$ where N_t is number of antenna at transmitter and N_r is number of antenna at receiver. Please note that the antenna spacing is negligible.

Next by squaring and differentiating between BSs and serving BS, BS_1, the new line i.e straight line method can be found. For BS_1 and BS_2, we found that for every n;

$$r_{1,n}{}^2 - r_{2,n}{}^2 - \|BS_1\|^2 + \|BS_2\|^2 = -2(x_u\left(x_1 - x_2\right) + y_u\left(y_1 - y_2\right)) \tag{4}$$

A similar LLOP can be generated for BS_1 and BS_3 for every n;

$$r_{1,n}{}^2 - r_{3,n}{}^2 - \|BS_1\|^2 + \|BS_3\|^2 = -2(x_u\left(x_1 - x_3\right) + y_u\left(y_1 - y_3\right)) \tag{5}$$

If there are more than three BSs involved, LLOP can be determined as same procedure as the above equation where for BS_1 and BS_i for every n;

$$r_{1,n}{}^2 - r_{i,n}{}^2 - \|BS_1\|^2 + \|BS_i\|^2 = -2(x_u\left(x_1 - x_i\right) + y_u\left(y_1 - y_i\right)) \tag{6}$$

Therefore, generally the above equations can be extended to i BS;

$$r_{j,n}{}^2 - r_{i,n}{}^2 - \|BS_j\|^2 + \|BS_i\|^2 = -2(x_u\left(x_j - x_i\right) + y_u\left(y_j - y_i\right)) \tag{7}$$

where;

$$\|BS_j\|^2 = x_j{}^2 + y_j{}^2; \quad j = 1$$

$$\|BS_i\|^2 = x_i{}^2 + y_i{}^2; \quad i = 2,\ldots,N$$

We could then find the position of MS by solving the new LLOP for each TOA signal among all BSs with BS1 as serving cell (reference BS). From equation (4), it can be simplified to

$$y_u = \frac{A_1 - x_u\left(x_1 - x_2\right)}{\left(y_1 - y_2\right)} \tag{8}$$

where $A_1 = \frac{1}{2}\left[r_{2,n}{}^2 - r_{1,n}{}^2 + \|BS_1\|^2 - \|BS_2\|^2\right]$

The same procedure is then applied to the equation (5) gives

$$y_u = \frac{B_1 - x_u\left(x_1 - x_3\right)}{\left(y_1 - y_3\right)} \tag{9}$$

where $B_1 = \frac{1}{2}\left[r_{3,n}{}^2 - r_{1,n}{}^2 + \|BS_1\|^2 - \|BS_3\|^2\right]$

By substituting equation (8) into equation (9); and solving for x-coordinate of x_u, we get

$$x_u = \frac{B_1\left(y_1 - y_2\right) - A_1\left(y_1 - y_3\right)}{\left(x_1 - x_3\right)\left(y_1 - y_2\right) - \left(x_1 - x_2\right)\left(y_1 - y_3\right)} \tag{10}$$

This can be generalised for any BS i in finding x-coordinate of x_u results

$$x_u = \frac{B_i\left(y_1 - y_i\right) - A_i\left(y_1 - y_{(i+1)}\right)}{C_i} \tag{11}$$

Following the same procedure for any $BS\ i$ in finding y coordinate of y_u is

$$y_u = \frac{A_i\left(x_1 - x_{(i+1)}\right) - B_i\left(x_1 - x_i\right)}{C_i} \tag{12}$$

where

$$A_i = \frac{1}{2}\left[r_{i,n}{}^2 - r_{1,n}{}^2 + \|BS_1\|^2 - \|BS_i\|^2\right]$$

$$B_i = \frac{1}{2}\left[r_{(i+1),n}{}^2 - r_{1,n}{}^2 + \|BS_1\|^2 - \|BS_{(i+1)}\|^2\right]$$

$$C_i = \left(x_1 - x_{(i+1)}\right)\left(y_1 - y_i\right) - \left(x_1 - x_i\right)\left(y_1 - y_{(i+1)}\right)$$

for $i = 1,2,\ldots N-1$

Thus, given the positions of the BSs and the range measurements,$r_i = ct_i$, an estimate of the MS's location can be obtained using (11) and (12). Also, note that this method can be used when there are measurement errors and the circles do not all intersect at a single point. However, in the case of MIMO, we consider all TOA signals in determining the position of the BSs. The number of intersection or optimal possible location estimation of MS can be determined by the following equation;

$$\varphi_{est} = \left(N_t \times N_r\right)^2 \times \left(N - 2\right) \tag{13}$$

It can be observed that the number of possible location estimation using this technique is greatly increased as compare to the CLOP (such as LLS algorithm). For example for the MIMO 2x1 system in which three BSs involved in estimating the position of MS, there are four possibilities of MS's position can be calculated. Therefore by averaging all the possibilities of MS position; an accurate of MS position can be achieved. Note that we assume no LOS and single scattering for all TOA paths. In other words, because the NLOS error is positive, the measured range is greater than true range and it is assumed that the measurement noise is a zero mean Gaussian random distribution with relatively small standard deviation and is negligible as compared to NLOS error.

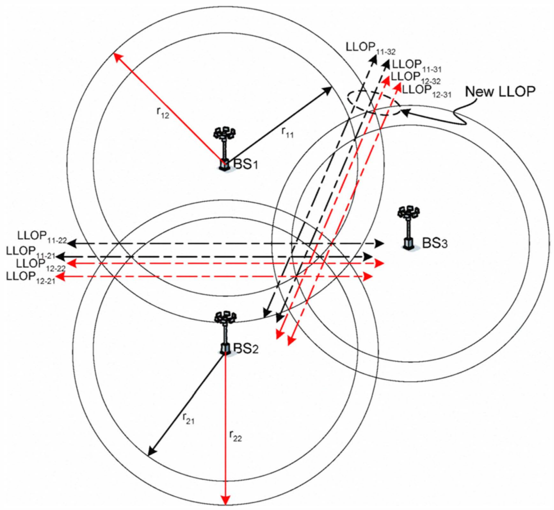

Fig. 3 Geometry of TOA-Based Location showing traditional CLOPs and New Technique of LLOPs for MIMO 2x1 with 3 BSs

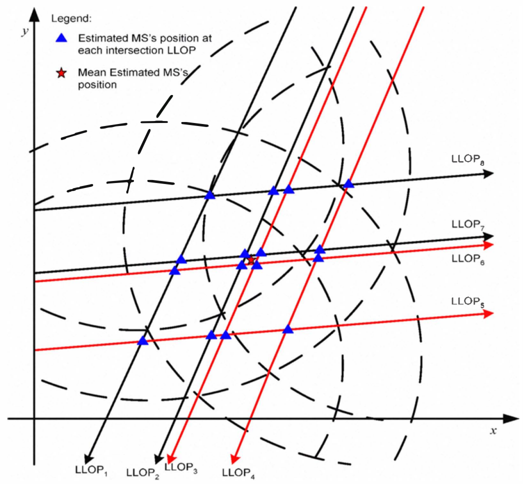

Fig. 4 Multiple LLOPs for MIMO 2x1

IV. SIMULATION RESULTS

The performance of the proposed algorithm is investigated via computer simulation where a comparison is made between SISO and various MIMO antenna mode configurations and the algorithm is also compared to LLS algorithm. In this work, the location estimation accuracy is checked for the situations of 3 BSs and simulations are performed under the assumption of macrocell cellular environments. The geometric coordinates of BSs are $BS1(x_1 = 500,\ y_1 = 3750)$, $BS2(x_2 = 2250,\ y_2 = 4500)$, $BS3(x_3 = 2250,\ y_3 = 3000)$,and the geometric coordinate of true MS is $MS(x_u = 1500,\ y_u = 3750)$. All units are expressed in meter. The simulated parameters have been selected similar to that IEEE802.16e downlink system and the dispersive delay properties of the channel can introduce range errors up to 600m [12]. Therefore, the NLOS range errors are modeled as positive random variables having support over [0, 600m], generated according to circular disk scatterer model (CDSM) [13]. The simulated location error has the total number of 1000 different data sets and the estimation MS position is obtained by averaging over all the 1000 estimates. The TOA measurements are created by calculating the true distance from a MS position to the known BS with MIMO capability and were each corrupted by NLOS errors.

Fig. 5 shows the cumulative distribution functions of the average RMSE location error of the algorithms for various antenna mode configurations when the range errors are generated using the CDSM model. It can be seen that under the case of MIMO antenna mode configurations, the LLOP algorithm perform very well than the LLS algorithm for the error model considered. Meanwhile, under the case of SISO antenna mode configuration, we can see that the performance both LLOP and LLS algorithms are nearly identical.

Simulations were performed to study how the average location error is affected by the number of BSs that do not have an LOS path to MS when LLOP algorithm are employed for various antenna mode configurations. Except for the case when all BSs are NLOS, the serving BS was assumed to be LOS with the MS. However, the algorithms do not have prior knowlegde of the LOS and NLOS status of the BSs. This performance also was compared with LLS algorithm as shown in the Fig. 6. As can be observed, the average location error increase with the number of NLOS BSs for SISO antenna, but the average location error for MIMO antennas only rises up with one NLOS BS and then it dramatically decreases when two and more NLOS BSs are involved. In other words, we can say that the MIMO antenna configurations are capable to mitigate the effect of NLOS errors. It can also be seen that LLOP algorithm performed better than LLS algorithm in spite of the number of NLOS BSs.

Finally, simulations were performed to examine how the LLOP algorithm compares against the LLS algorithm for various antenna mode configurations when upper bound on uniform error is varied. Fig. 7 shows the average RMSE location erros versus the upper bound on uniform NLOS error,U_N. It can be observed that the performance of MIMO antenna mode configurations using the LLOP algorithm are much better than the MIMO antenna mode configurations using the LLS algorithm whereas performance for SISO antenna mode configurations is nearly similar for both algorithms. It has been shown that the LLOP algorithms can further improve the accuracy of location estimation with MIMO antenna mode configurations.

V. CONCLUSIONS

In this paper we presented a geometrical approach using new LLOP technique for MIMO antenna mode configuration in IMT-Advanced networks for location estimation with range measurements from only three BSs in the NLOS environments and their performances have been compared with SISO antenna. The technique utilizes relationships drawn from the geometry of the BSs and ranges linear LOP, and it does not require discrimination between LOS and NLOS range measurements. The geometrical solution found the intersection of the LLOPs and used the mean of those intersections to find better location estimation. Simulation results showed the

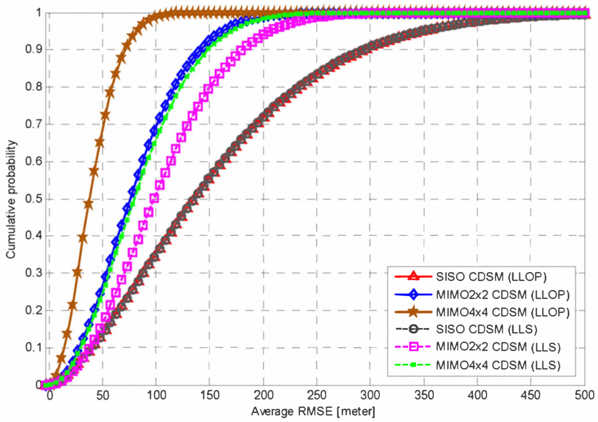

Fig. 5 The CDF of the Location Error of the LLOP and LLS algorithms for Different Antenna Mode Configurations on the CDSM Model

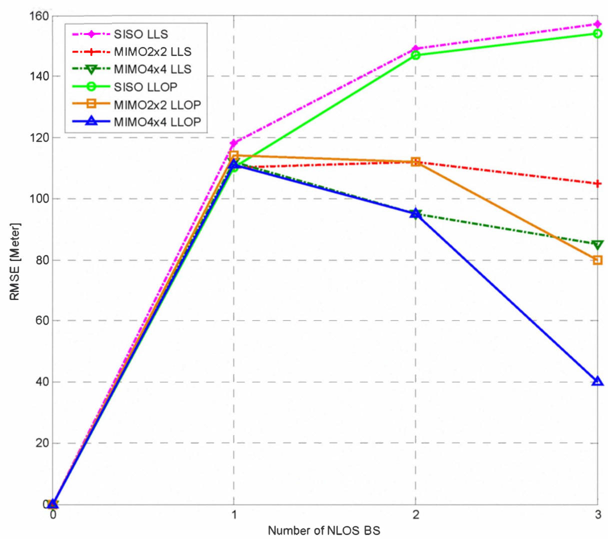

Fig. 6 Average RMSE For Different Antenna Configurations Versus the Number of NLOS BSs

location estimation accuracy of new LLOP was much better when compared to that of the LLS for MIMO antenna mode configurations. It was observed that the average location error for MIMO antennas decrease when two and more NLOS BSs were involved. Simulations also showed that the upper bound of the uniform error distribution have an influence on the location estimation accuracy The location error of New LLOP for various MIMO antenna mode configurations is less than 0.1km for 67% of the time, and less than 0.17km for 95% of the time. The results of the simulation compliance to the location accuracy demand of E-911 requirements [14]. Hence it is proven that enabling the MIMO antenna mode configurations in IMT-Advanced positioning systems using LLOP algorithm can further improve their location accuracy even in the severe NLOS conditions.

ACKNOWLEDGEMENTS

The author wishes to thank Universiti Teknikal Malaysia Melaka (UTeM) for the sponsorship.

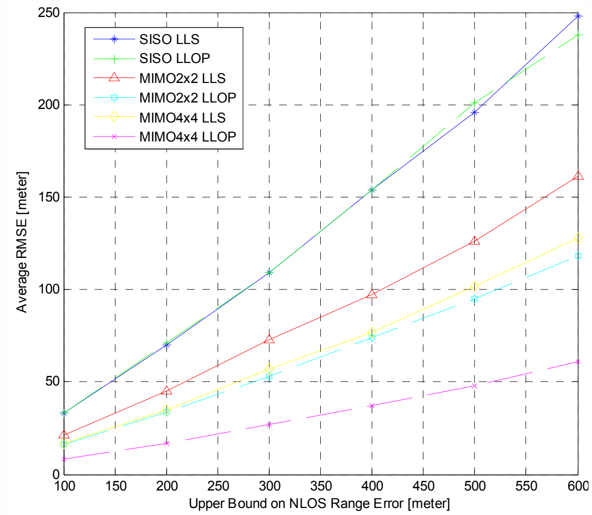

Fig. 7 Average RMSE Location Erros versus the Upper Bound on Uniform NLOS Error

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