September 13, 2001

Ms. Magalie Roman Salas, Esq.
Secretary
Federal Communications Commission
445 12th Street, N.W.
Washington, DC 20554

EX PARTE
In the Matter of CC Docket No. 94-102
Comments of LOCUS Corporation in Japan on Performance, Viability, and Application of the Mobile-Assisted Network Location System of AT&T Wireless

Dear Ms. Salas:

LOCUS Corporation in Japan ("LOCUS") hereby submits the following *ex parte* comments on the Mobile-Assisted Network Location System ("MNLS"), as related to AT&T Wireless, Inc.'s ("AT&T") request for waiver.

LOCUS has recently succeeded in developing a new positioning technology for ordinary cellular phones under the guidance of and in collaboration with Sophia University in Japan. This system is a fusion of a new Advanced Maximum-Likelihood Estimation ("AME"), AOA, ESS, and BS-ID methods.

LOCUS intends to stress that MNLS is the most efficacious method for TDMA cellular phone to meet the mandate of E-911. This view is based on the fact that LOCUS has successfully deployed positioning services for more than forty months in Japan by exploiting an Enhanced Signal Strength ("ESS") method which is similar to MNLS but more appropriate for Personal Handy-phone Systems ("PHS").

LOCUS is confident of supporting and improving AT&T's MNLS so as to comply with E-911 regulation.

If we can be of further assistance to the Commission, please feel free to contact us.

Sincerely yours,

Hiroaki Kôshima
President
LOCUS Corporation
Muraki Bldg., 1-16-20,
Minami-senba, Chuoku.
Osaka-shi, Osaka 542-0081
Japan

Email address: koshima@ff.iij4u.or.jp
Phone: +81+6+6265+9061
Fax: +81+6+6265+9060

BEFORE THE
FEDERAL COMMUNICATIONS COMMISSION
WASHINGTON, D.C. 20554

In the Matter of	)	
	)	
Wireless E9-1-1 Phase II Automatic	)	CC Docket No. 94-102
Location Identification Requirements	)	
	)	
	)	

To the Commission:

EX PARTE COMMENTS OF LOCUS CORPORATION

On Performance, Viability, and Application of the Mobile-Assisted Network Location System (MNLS)

1 INTRODUCTION

LOCUS Corporation in Japan (" LOCUS") submits these *ex parte* comments for the purpose of assisting the Commission in its evaluation of an April 4, 2001 request by AT&T Wireless Services ("AT&T Wireless") for a waiver[1]. In its April 4 request, AT&T Wireless proposed the use of Mobile-Assisted Network Location System ("MNLS") technology to meet the E-911 Phase II mandate for its TDMA network.

On May 10, the FCC ordered AT&T Wireless to produce, by May 30, the test data that led to its conclusions and supported its April 4 request to use MNLS technology as its location solution[2].

On May 30, AT&T Wireless, in a partial response to the FCC's May 10 order, submitted documentation in support of its request for waiver[3].

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[1] AT&T Wireless Services, Inc. Request for Waiver of the E911 Phase II Location Technology Implementation Rules, CC Docket No. 94-102, filed April 4, 2001.

[2] *Revision of the Commission's Rules to Ensure Compatibility with Enhanced 911 Emergency Calling Systems*, CC Docket No. 94-102, Order, DA 01-1188, released May 10, 2001.

[3] Partial Response of AT&T Wireless Services, Inc. to Order of the Wireless Telecommunications Bureau, CC Docket No. 94-102, filed May 30, 2001.

2 ABOUT LOCUS CORPORATION AND LOCATION BASED SERVICES IN JAPAN

LOCUS Corporation was incorporated in 1995 as a positioning development venture in Japan and launched the world's first commercial deployment on April 15, 1998. Since then LOCUS has successfully provided subscribers with Location Based Services ("LBS") with its original positioning technology exploiting Enhanced Signal Strength ("ESS")[4] method.

LOCUS has granted licenses to the Japanese government and many leading handset-makers in Japan. The Japanese Government and district governments awarded LOCUS grants for developing its positioning systems.

Various types of positioning systems are now available in Japan. Some of these are BS-ID, Signal Strength ("SS"), ESS, and gpsOne. Positioning accuracy spreads from 10m to several kilometers depending on systems.

In Japan there is no mandate such as E-911, but a number of Alzheimer patients wearing LOCUS handsets have been rescued in urban, suburban and rural areas. The pain of families supporting patients with youthful or senile orientation disorders has been relieved. Children have been easily located and monitored by their parents with i-mode (a service of NTT DoCoMo) in cellular handsets. Today, journalists no longer write articles about lost Alzheimer patients being saved by LOCUS technology, because it is a matter of daily occurrence here.

Groups of high school students touring Tokyo and Kyoto usually carry these positioning handsets to prevent them from getting lost. Tourist guides find them very valuable.

Young people are locating shops and places of amusement by using handsets to refer their positions. Luxury car owners feel comfortable by installing those devices inside their cars for anti car-theft.

In spite of absence of accuracy regulation, people are enjoying benefits of safety and fun as mentioned above.

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[4] H. Koshima & J. Hoshen, "Personal Locator Services Emerge", SPECTRUM of IEEE, February, 2000 Issue, pp. 41~48.

3 A PROPOSAL TO FCC BY LOCUS

This proposal was written after reading the letters[5, 6, 7, 8, 9,10,11,12] to FCC related to AT&T Wireless's request for waiver. MNLS is fundamentally an excellent solution for positioning systems of IS-136, because it makes many legacy handsets usable for E-911.

In order to locate mobile handsets by exploiting MNLS accurately, adoption of Probability Theory is indispensable. This is because fluctuations of signal strength affected by reflection, shadowing and diffraction caused by terrain, buildings, vehicles and human bodies tend to deteriorate accuracy of location of handsets. However, conventional probability theory solution requires many complicated calculations of integral calculus and therefore it takes long time for fixing position.

The Advanced Maximum-Likelihood Estimation ("AME") technology newly developed by LOCUS features the following:

1. AME does not require above-mentioned complicated calculations of integral calculus. This contributes to shortening time for calculation.
2. As a profile of each grid within a cell or as a profile of each base station at least, information on terrain, clutter and deviation of signals is taken into account. The profile primarily consists of propagation exponent and standard deviation. These lead to higher accuracy.

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[5] Ericsson Inc., Comments of Ericsson, filed May 7, 2001.

[6] SigmaOne Communications Corporation, Comments of SigmaOne in response to Request for Waiver of AT&T Wireless Services, Inc., filed June 8, 2001.

[7] Shook, Hardy & Bacon LLP, SigmaOne Comments on AT&T Wireless Services Request for Waiver, filed June 14, 2001.

[8] U.S. Wireless Corporation, EX PARTE Comments of U.S. Wireless Corporation on Performance, Viability, and Application of the Mobile-Assisted Network Location System (MNLS), filed July 11, 2001.

[9] Willkie Farr & Gallagher, "Analysis of the Performance and Viability of the Mobile-Assisted Network Location System (MNLS) " by TruePosition, Inc., filed July 23, 2001.

[10] Shook, Hardy & Bacon LLP, "Comments in response to AT&T Wireless' July 13 *ex parete* presentation and submits B to this *ex parte* in response to U.S. Wireless *ex parte* comments from July." by SigmaOne, filed July 24, 2001.

[11] U.S. Wireles Corporation, MNLS Performance Analysis, issued August 7, 2001.

[12] Crispin & Brenner, P.L.L.C., Oral Ex Parte Presentation CC Docket No.94-102, on behalf of Qualcomm Incorporated, filed August 13, 2001

3. Also, the profiles can be refined further by study-functionality of the system.
4. Required investments to networks are minimized.

3 TECHNICAL BACKGROUND

LOCUS can substantially contribute to accuracy improvement for TDMA cellular systems, such as IS-136, with an advanced technology consisting of Advanced Maximum-Likelihood Estimation ("AME"), ESS and BS-ID. Before entering discussion on the advanced technology, a brief description on ESS is given.

For PHS, LOCUS has been providing positioning systems based on ESS. These systems have proven satisfactory in terms of accuracy and other performance, but the cells are micro-cells, and radiuses of cell range from 150m to 2km depending on types of base stations.

PHS has TDMA radio interface technology, and it is equipped with a hand off function similar to MAHO as main stream functionality. Mobile handsets collect BS-IDs and respective signal levels of proximity base stations. A distance R between a mobile handset and a base station is indicated as the following equation.

$$L = A - 10\,\alpha \log R$$

Where L is received signal strength in dB, A is signal strength in dB at unit distance from the base station defined by Effective Radiated Power ("ERP"), antenna gain and antenna height of transmitter, frequency and antenna gain of mobile handsets. α is Signal Propagation Exponent defined by terrain and clutter at a radiated frequency, and R is range between the handset and the base station in meter.

Usually propagation exponent α is unknown, therefore procedures of calculating α by measuring the real world have to be taken in advance in order to estimate the distance R accurately corresponding to each signal strength L.

By the end of 1997, LOCUS completed data base of propagation pattern of signals transmitted from each base station using α for each grid of 5m x 5m or 50m x 50m inside a cell of respective base stations belonging to a PHS carrier. Simulation of signal propagation was made with three-dimensional digital maps.

Within one second, positioning work is done by taking advantage of trilateral or pentangular method, after three to five BS-Ids, and signal strength data sent from

mobile handsets through data channels of PHS are received at the positioning center. Typical accuracy data is shown in figure 1, and this accuracy has been good enough for locating Alzheimer patients, for example. ESS works well even inside buildings. Actually, many senile people have been saved inside large public buildings.

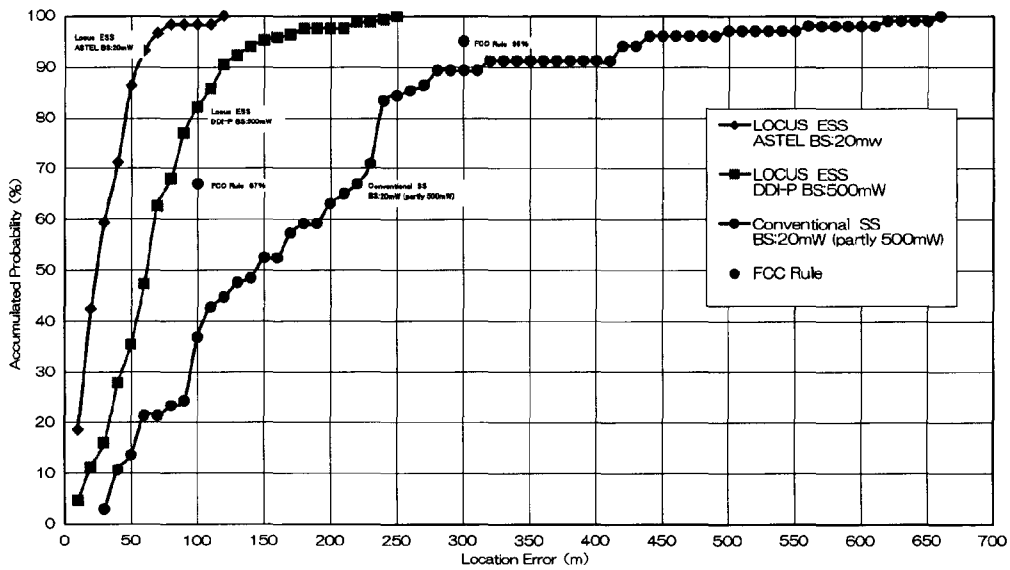

Figure 1 Accuracy data by ESS and SS for PHS

4 THE ADVANCED TECHNOLOGY

The advanced technology that LOCUS has newly developed is the fusion algorithm of AME, AOA, ESS and BS-ID. ESS was described above, and AOA and BS-ID methods are well known.

Advanced Maximum-Likelihood Estimation ("AME") Method

In this section, a new positioning technology taking advantage of the Advanced Maximum-Likelihood Estimation ("AME") method is described.

4.1 Probability density function of the short-term median

The long-term median Γ_{im} at an arbitrary position of a mobile handset x_s at a distance of d_i from a base station BS_i is indicated as

$$\Gamma_{im} = h(d_i) \tag{1}$$

where $h(d_i)$ is propagation estimation equation from the base station.

Assume that Received Signal Strength ("RSS") (the short-term median) Γ_i fluctuates by buildings, vehicles, body-effect, and other factors around the long-term median Γ_{im} in accordance with probability theory in the vicinity of the position x_s.

The probability density function of the short-term median Γ_i is indicated as below.

$$p_{xs}(\Gamma_i) = f(\Gamma_i, \sigma_i, x_s) \cdots for \quad i = 1,2,,n \tag{2}$$

σ_i is standard deviation and here, x_s is an estimation parameter but not a probability variable. Ranges of possible x_s are taken arbitrarily.

The equation (2) does not signify conditional probability, but probability with the parameter x_s.

4.2 The long-term median

If the long-term median Γ_{im} is conformed to Okumura's curve, the following equation is given.

$$\Gamma_{im} = A_i - 10\alpha_i \log d_i \tag{3}$$

A_i is the same constant as defined in section 3. α_i is an attenuation exponent of propagation from each base station and the value of α_i is 2~5 in general.

In the case that the short-term median performs as a decibel normal distribution, probability density function of variable Γ_i is indicated as below,

$$p_{xs}(\Gamma_i) = \frac{1}{\sqrt{2\pi\sigma_i^2}} \exp\left\{-\frac{(\Gamma_i - \Gamma_{im})^2}{2\sigma_i^2}\right\} \cdots for \quad i = 1,2,,n \tag{4}$$

where x_s is unknown position of a mobile handset.

4.3 The combined probability density function of RSS from plural base stations

Given a position x_s, the distances from the position to each base station are fixed as $d = (d_1, d_2,,, d_n)$.

Figure 2 shows positions of base stations and a mobile handset. x_s shows position of the mobile handset. $d_1, d_2,,,,,, d_n$ signify distances between the mobile handset and each base station.

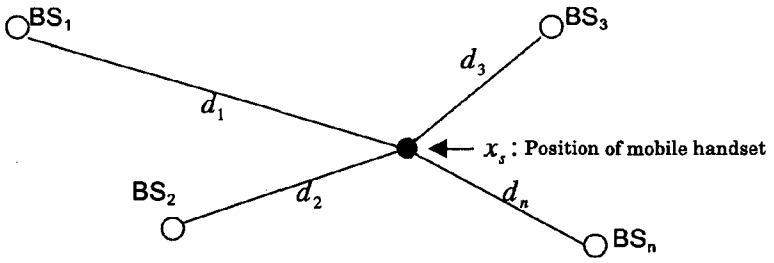

Fig. 2 BSs and mobile handset

All received signal strengths from each base station are indicated as $\Gamma = (\Gamma_1, \Gamma_2,,, \Gamma_n)$. Then the combined probability density function is

$$p_{xs}(\Gamma) = p(\Gamma_1, \Gamma_2,,, \Gamma_n) \tag{5}$$

If the receiving probability is independent with each base station, the combined probability density function is

$$p_{xs}(\Gamma) = p(\Gamma_1) \cdot p(\Gamma_2) \cdot \cdots \cdot p(\Gamma_n) \tag{6}$$

From equation (6), likelihood function is derived as equation (7).

4.4 Likelihood function

Integrating RSS data $\Gamma = (\Gamma_1, \Gamma_2,,, \Gamma_n)$ measured at x_s for $\pm\Delta$, likelihood function is

$$L_{xs}(\Gamma_1, \Gamma_2,,, \Gamma_n) = \int_{\Gamma=\Gamma_1-\Delta}^{\Gamma_1+\Delta} p_1(\Gamma) d\Gamma \cdot \int_{\Gamma=\Gamma_2-\Delta}^{\Gamma_2+\Delta} p_2(\Gamma) d\Gamma \cdot \cdot \int_{\Gamma=\Gamma_n-\Delta}^{\Gamma_n+\Delta} p_n(\Gamma) d\Gamma \tag{7}$$

Each term of equation (7) is

$$0 \le \int_{\Gamma=\Gamma_i-\Delta}^{\Gamma_i+\Delta} p_i(\Gamma) d\Gamma \le 1 \tag{8}$$

Hence,

$$0 \le L_{xs}(\Gamma_1, \Gamma_2,,, \Gamma_n) \le 1 \tag{9}$$

After calculating equation (7) for all points, x_s which gives maximal value is the Maximum Likelihood Estimation ("MLE"). The position with maximal value of x_s can be regarded as the position of the mobile handset.

To calculate equation (7), equation (4) is changed with the logarithm as below.

$$l_{xs} p(\Gamma_i) = -\frac{1}{2} l(2\pi\sigma_i^2) - \{\frac{(\Gamma_i - \Gamma_{im})^2}{2\sigma_i^2}\} \tag{10}$$

Equation (6) is changed with the logarithm as well.

$$l_{xs}p(\Gamma) = lp(\Gamma_1) + lp(\Gamma_2) + ... + lp(\Gamma_n) \tag{11}$$

Substituting equation (10) to equation (11),

$$l_{xs}p(\Gamma) = -\frac{1}{2}l(2\pi\sigma_1^2) - \{\frac{(\Gamma_1 - \Gamma_{1m})^2}{2\sigma_1^2}\} - \frac{1}{2}l(2\pi\sigma_2^2) - \{\frac{(\Gamma_2 - \Gamma_{2m})^2}{2\sigma_2^2}\} \quad \cdots \quad \cdots$$

$$-\frac{1}{2}l(2\pi\sigma_n^2) - \{\frac{(\Gamma_n - \Gamma_{nm})^2}{2\sigma_n^2}\} \tag{12}$$

By making Γ constant and x_s variable, the logarithmic likelihood function is

$$j_{xs}(\Gamma) \equiv -\frac{1}{2}\sum_{i=1}^{n} l(2\pi\sigma_i^2) - \sum_{i=1}^{n}\{\frac{(\Gamma_i - \Gamma_{im})^2}{2\sigma_i^2}\} + nl2\delta \tag{13}$$

Maximum Likelihood Estimation ("MLE") is obtained by selecting $\hat{x}_s$ which makes the logarithmic likelihood function maximal.

$$\hat{x}_s = \arg\{\max_{xs} j_{xs}(\Gamma)\} \tag{14}$$

The Maximum Likelihood Estimation ("MLE") with real value is

$$\hat{x}_s = \arg\{\max_{xs} L_{xs}(\Gamma)\} \tag{15}$$

4.5 Calculation of position

(1) As has been done in ESS solution, each cell is divided into many grids as large as 5m x 5m or 50m x 50m, or, even with height when inside tall buildings, i.e. 5m x 5m x 5m.

(2) Propagation exponent α and standard deviation σ are obtained by measuring propagation data in the real world.

(3) By exploiting RF propagation simulation software associated with three-dimensional digital maps having terrain and clutter, a set of the long-term median i.e. $\Gamma_m = (\Gamma_{1m}, \Gamma_{2m},,,,,\Gamma_{nm})$ in each grid is assigned. Some measurements of Γ_m at each position of x_s in the real world would contribute to accuracy improvement.

(4) With observed data of the short-term median $\Gamma = (\Gamma_1, \Gamma_2,,,,\Gamma_n)$ at unknown position x_s, the logarithmic likelihood function of equation (13) is computed. Equation (13) is a type of simple summation, hence it can be computed more quickly and simply than using complicated integral calculus.

(5) By computing all likelihood estimations for each x_s, the position of x_s, of which likelihood estimation is largest, is fixed as the place where the mobile handset exists by the Maximum Likelihood Estimation ("MLE") theory.

4.6 Theoretical and empirical test results

Figures 3, 4 and 5 theoretically show three-dimensional expressions of Likelihood Function. Advanced Maximum-Likelihood Estimation ("AME"), is applicable in the case of one or two base stations as shown in Figure 4 and 5.

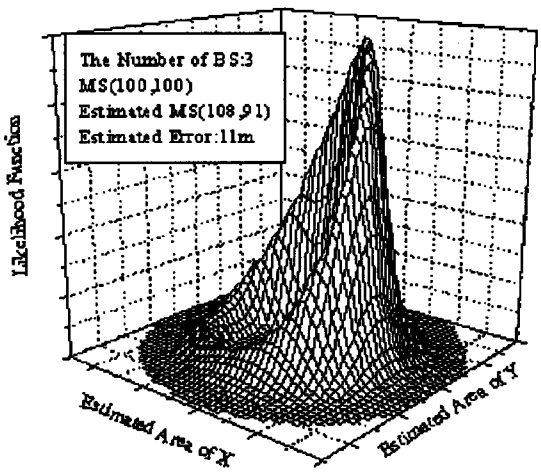

Fig.3 Distribution of Likelihood Value (# of Base Stations : 3)

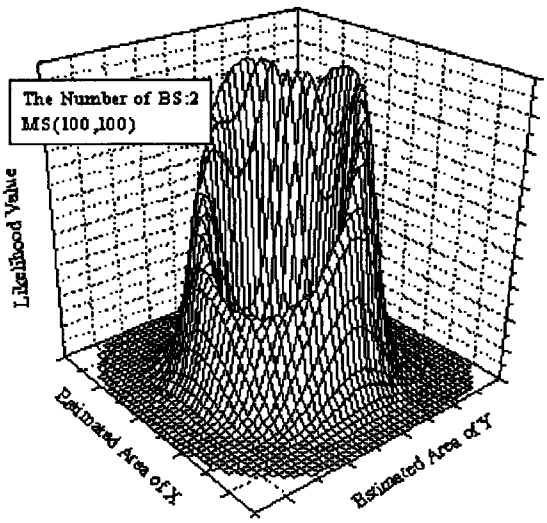

Fig.4 Distribution of Likelihood Value (# of Base Stations : 2)

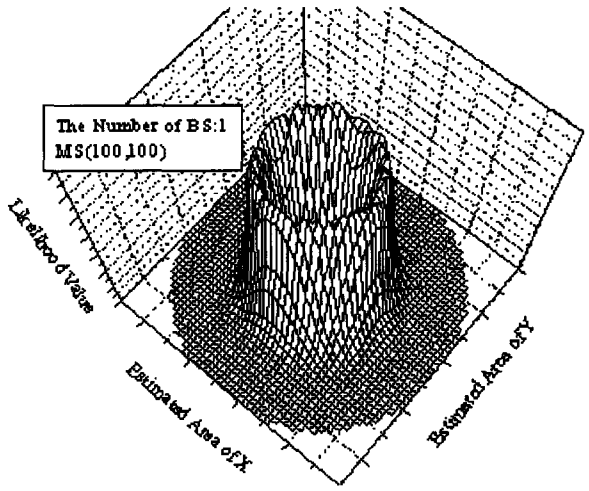

Fig.5 Distribution of Likelihood Value (# of Base Station : 1)

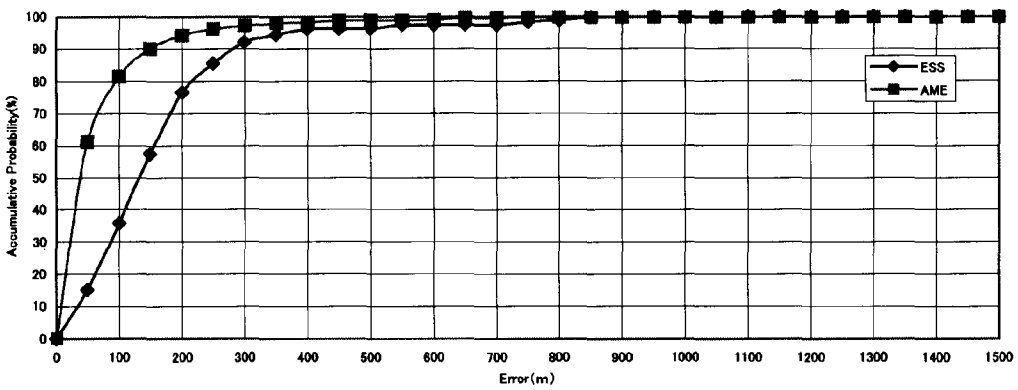

Figure 6 A Comparison of Accuracy of ESS and AME

Figure 6 shows a comparison of accuracy empirically obtained by ESS and AME. Significant improvement in accuracy is observed with AME comparing with conventional ESS. Three base stations in the vicinity of mobile handset for the test were used in each case. The more base stations are used, the higher accuracy can be expected.

In these tests, neither sector information nor AOA information were introduced. Furthermore, if the profiles of each grid or base station are refined by daily study-functionality of the system, accuracy will be much improved, day by day.

One of the main reasons why accuracy of AME is superior to conventional estimation method is by taking advantage of the Determinism Theory in addition to the Probability Theory. Related discussion on Cramér-Rao's Lower Band[7] is provided in Exhibit A.

5 CONCLUSION

The Advanced Maximum-Likelihood Estimation ("AME") for MNLS has proven an excellent positioning solution. Considerable improvement of AME in accuracy can be expected by increasing number of base stations to be observed, by adopting sector information, and by exploiting study-functionality.

The fusion technologies of AME, AOA, ESS and BS-ID feature as below:

(1) The fusion of AME, AOA, ESS and BS-ID can provide high accuracy to comply with FCC mandate, and it can be improved in accuracy, day by day, with daily study-functionality,.

(2) Several tens of millions of people currently having legacy handsets for IS-136 can get benefit of E-911.

(3) Necessary investments required to carriers are minimized.

In addition, LOCUS has much of know-how in areas such as signal propagation phenomena along roads etc. These results were achieved because LOCUS has successfully deployed commercial Location Based Services ("LBS") for more than forty months.

LOCUS confidently believes that the fusion of AME, AOA, ESS ad BS-ID will support and improve positioning accuracy of MNLS so as to comply with the regulations of E-911. The concept of AME is also effective for Analog Cellular and E-OTD for GSM. Verification and confirmation of these improvements require empirical tests of the fusion of AME, AOA, ESS and BS-ID in the U.S. as soon as possible.

We welcome contacts from any carriers and handset makers of cellular phones in the U.S. and collaboration with them as well.

Respectfully submitted,

Hiroaki Koshima

President

LOCUS Corporation (in Japan)

Muraki Bldg., 1-16-20, Minami-senba,

Chuo-ku, Osaka-shi, Osaka 542-0081

Japan

Email: koshima@ff.iij4u.or.jp

Phone: +81+6+6265+9061

Fax: +81+6+6265+9060

September 13, 2001

Exhibit A

As for the investigation with Cramér-Rao's Lower Border[7]

For positioning estimation in general, the Probability Theory, the Determinism Theory, and The Fusion are exploited. Cramér-Rao's Lower Border is applicable in the case of the Gaussian Probability theory. Since both MNLS and TDOA fundamentally have similar distribution problems, it can not be asserted that either is advantageous over the other in terms of Cramér-Rao's Lower Border.

AME is taking advantage of the fusion of the Probability and the Determinism theories, It can make parameters more accurate by the Determinism Theory, so Cramér-Rao's Lower Border is not applicable.

In conclusion, it is not always correct to evaluate different solutions of positioning estimation with Cramér-Rao's Lower Border, because conditions are different in each case.