

# Performance Comparison of Multipath Channel Estimation Algorithms with 28 GHz Channel Measurements

Jinyi LIANG, Juyul LEE, Myung-Don KIM, Jae-Joon PARK, Bonghyuk PARK

Wireless Applications Research Department, ETRI (Electronics and Telecommunications Research Institute)  
218, Gajeongno, Yuseong-gu, Daejeon, Korea

{liangjinyi, juyul, mdkim, jjpark, bhpark}@etri.re.kr

**Abstract**— To analyze multipath propagation channels from field measurement data, multipath parameter extraction algorithms are utilized. Among them, the Space-Alternating Generalized Expectation-maximization (SAGE) provides high-resolution performance on parameter estimations although it requires high computational complexity. On the other hand, Bartlett Beamformer (BBF) with low complexity is known to provide comparatively lower resolution for channel parameter estimation. In this paper, we investigate the performance of SAGE and BBF with our 28 GHz field measurement data in terms of dispersion characteristics such as delay spread and angular spread. The performance of two algorithms is evaluated by comparison of standard deviation of estimated parameters. We also compare the computation time of each algorithm even the iterative algorithm such as SAGE is complicated to count algorithm complexity. Our results show that the angular spread values obtained, respectively, by SAGE and BBF are similar. On the other hand, the delay spread values obtained by the two methods has small difference. In terms of computational complexity, our simulation results show that BBF can save 99% computation time comparing to the SAGE.

**Keywords**— Bartlett beamformer, SAGE, millimetre wave propagation, channel measurement, and multipath channel.

## I. INTRODUCTION

Realistic propagation channels can be produced with channel models parameterized by propagated power, delay, spatial direction, Doppler frequency, etc. To build an accurate channel model, characterization of the channel parameter distributions from massive measurement data is important. Practically, the process for channel characterization using measured data requires low-complexity as well as high-resolution performance.

High-resolution parameter estimation algorithms, such as Space-Alternating Generalized Expectation-maximization (SAGE) [1], Multiple Signal Classification (MUSIC) [2] and Richter's Maximum likelihood estimation (RiMAX) [3], etc., can provide very accurate estimation results with the cost of high computational complexity. Alternately, the Bartlett Beamformer (BBF), which requires relatively lower computational power, can be considered [4][5].

Therefore, our focus in this paper is how accurate we can estimate channel parameters with the BBF technique compared with the high-resolution algorithms. In this paper, we compare the performance of SAGE and BBF with our 28 GHz measurement data in terms of dispersion parameters e.g. delay spread and angular spread. The performance will be evaluated by comparison of the large scale parameters derived by the two algorithms, and computation complexity.

## II. MEASUREMENT SYSTEM AND SCENARIO

### A. Measurement System

The measurement campaign is performed using the millimeter-wave Band Exploration and Channel Sounder (mBECS) system, which was developed by Electronics and Telecommunications Research Institute (ETRI), Korea. The specifications of mBECS system are listed in Table 1.

TABLE 1. SPECIFICATIONS OF MBECS SYSTEM

| Characteristics              | Configurations |
|------------------------------|----------------|
| Center Frequency             | 28 GHz         |
| Bandwidth                    | 500 MHz        |
| PN Code Length               | 4095 chips     |
| Sliding factor               | 12500          |
| Receiver chip rate           | 499.96 MHz     |
| TX Output Power (max.)       | 29 dBm         |
| Multi-path Resolution        | 2ns (0.6m)     |
| Automatic Gain Control Range | <60 dB         |

### B. Measurement Scenario

The measurement campaign was conducted in an office environment. Figure 1 shows the layout of the office and the height (from floor to ceiling) is 3 meters. The office area "O1" and "O2" on the right and the entrance hall located at the bottom are connected with the corridor "C1" and "C2". During the measurement, the TX was fixed in the entrance hall, and the RXs are located in three positions including one Line-of-Sight (LoS) position "L" and two Non-Line-of-Sight (NLoS) positions "N1" and "N2" sequentially (Figure 2). Both the TX and RX antennas are positioned at 1.5 meters high. The environment was kept stationary without any moving objects.

The TX antenna is a horn antenna with 30° Half Power Beam Width (HPBW) and the direction of the antenna was fixed and directing to “L”. The RX antenna is an antenna with 10° HPBW. During the measurement, the RX antenna was rotated horizontally with a 10° increment at different elevations: -10°, 0° and 10°. For each elevation angle direction, the RX horn antenna would point at  $n$  different azimuth directions (in our case,  $n=36$ , i.e., 0°, 10°, 20°, ..., 350°) sequentially.

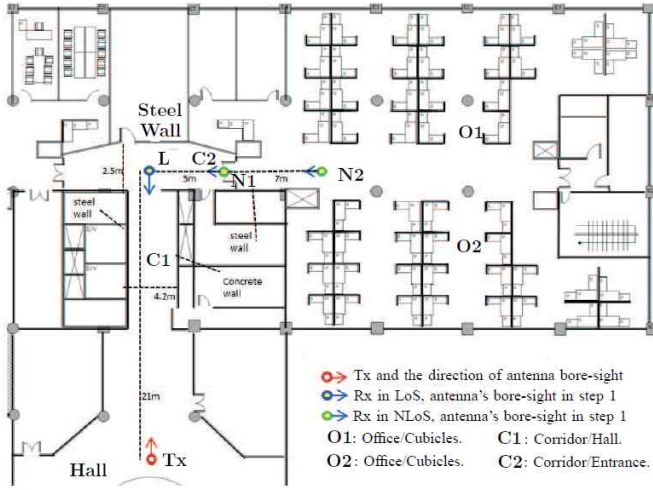


Figure 1. Layout of the measurement site.



(a) TX



(b) RX at “L”



(c) RX at “N1”



(d) RX at “N2”

Figure 2. The photos of the measurement site

### III. PARAMETER ESTIMATION ALGORITHMS

If we consider delay, Azimuth of Arrival (AoA) and attenuation coefficient as the channel multipath parameters, the signal model can be written as:

$$y_n(t) = \sum_{l=1}^L \alpha_l c_n(\Omega_l) u(t - \tau_l) + w_n(t), t \in [0, T] \quad (1)$$

, where  $y_n(t)$  and  $c_n$  are the output and radiation pattern of the RX antenna directing to the  $n$ th direction, respectively.  $\alpha_l$ ,  $\Omega_l$  and  $\tau_l$  represent the complex attenuation, AoA and delay of the  $l$ th path respectively. The total number of paths is denoted by  $L$ ,  $u(t)$  is the transmitted signal,  $w_n(t)$  is white Gaussian noise.

#### A. SAGE

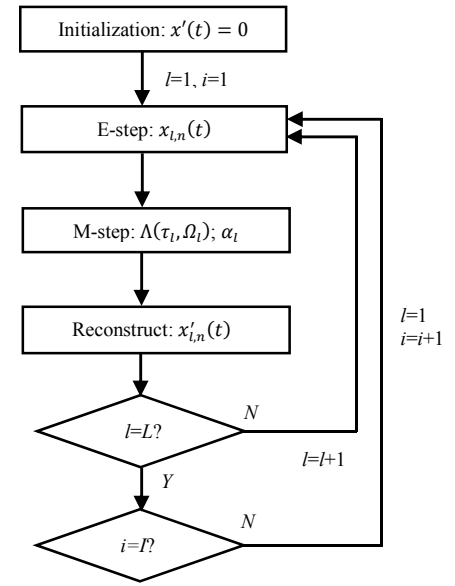


Figure 3. Flow chart of SAGE algorithm

Based on (1), SAGE can generate maximum likelihood estimates of the parameters ( $\alpha_l$ ,  $\Omega_l$  and  $\tau_l$ ) by updating the subsets of parameters iteratively [1]. In Figure 3,  $x$  is hidden data space which is defined as the contribution of individual propagation paths, i.e.  $x = x_l(t)$ , in which  $i$  is the current iteration number and  $I$  is the total iteration number.

In the E-step, the hidden data  $x_i(t)$  can be derived by dividing other reconstructed paths from complete data  $y$ :

$$x_{l,n}(t) = y_n(t) - \sum_{j \neq l} x'_{j,n}(t) \quad (2)$$

In the M-step, the maximum likelihood function of delay, and AoA can be calculated as:

$$\Lambda(\tau_l, \Omega_l) = G(\Omega)^{-1} \left| \sum_{n=1}^N c_n^*(\Omega) \int_0^T x_{l,n}(t) u^*(t - \tau) dt \right|^2 \quad (3)$$

, where  $()^*$  is the complex conjugate, and the normalization factor  $G(\Omega)$  can be calculated as:

$$G(\Omega) = \|c(\Omega)\|^2 \int_0^T |u(t)|^2 dt \quad (4)$$

The complex attenuation can be calculated with the given delay  $\tau_l$  and AoA  $\Omega_l$ :

$$\alpha_l = G(\Omega_l)^{-1} \sum_{n=1}^N c_n^*(\Omega_l) \int_0^T x_{l,n}(t) u^*(t - \tau_l) dt \quad (5)$$

Once the  $\alpha_l, \tau_l$  and  $\Omega_l$  are obtained, the  $l$ th path data can be reconstructed as:

$$x'_{l,n}(t) = \alpha_l c_n(\Omega_l) u(t - \tau_l) \quad (6)$$

In this paper, we limit the total estimation path number with 100 for LoS cases and 200 for NLoS. We set the total iteration number to 5 for SAGE runs.

The power range is calculated:

$$PR_{SAGE} = \min(\max(|\alpha_l|^2) - \min(|\alpha_l|^2), 20, L_n + 3) \quad (7)$$

$$L_n = \max(w_n(t))$$

, where  $L_n$  is the noise level. The multipath components that above and below this range are excluded from the SAGE results.

## B. BBF

According to BBF [6], the channel impulse response of delay and AoA can be calculated as:

$$h(\tau, \Omega) = \|c(\Omega)^2\|^{-1} \sum_{n=1}^N h_n(\tau) c_n^*(\Omega)$$

$$= G(\Omega)^{-1} \sum_{n=1}^N c_n^*(\Omega) \int_0^T y_n(t) u^*(t - \tau) dt \quad (8)$$

After setting a threshold  $P_t$  on the power of  $h(\tau, \Omega)$ , we can extract the multipath parameters of each path:

$$P(\tau, \Omega) = |h(\tau, \Omega)|^2 \quad (9)$$

$$\begin{cases} \tau_l = \tau |P(\tau, \Omega) > P_t \\ \Omega_l = \Omega |P(\tau, \Omega) > P_t \\ \alpha_l = h(\tau_l, \Omega_l) \end{cases} \quad (10)$$

To make the comparison between SAGE and BBF be fair, the threshold level is adjusted to:

$$P_t = \max(P(\tau, \Omega)) - PR_{SAGE} \quad (11)$$

## IV. RESULTS

The comparison of the estimation results from SAGE and BBF are illustrated in this section. Figure 4 shows the multipath components founded by BBF and SAGE, in which the received power level was shown. It can be observed that multipath components founded by BBF: Figure 4 (a), (c) and (e) are similar with the ones founded by SAGE: Figure 4 (b), (d) and (f) respectively. To derive the quantified results, we used delay spread (DS) and angular spread (AS) of the multipath components to compare the performance of SAGE and BBF.

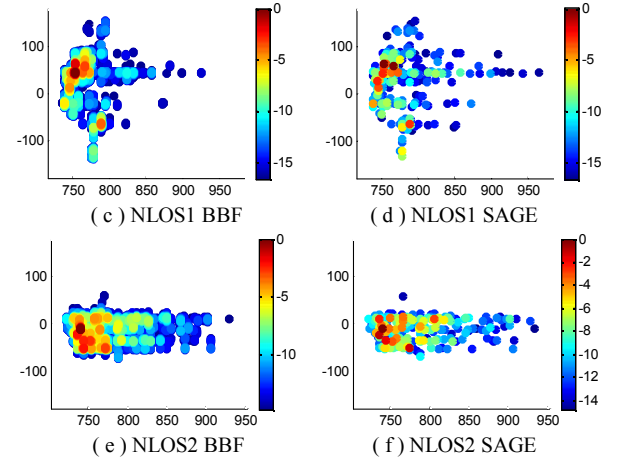
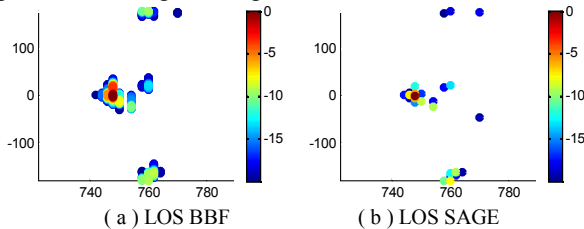


Figure 4. Founded paths by using BBF and SAGE when elevation=0

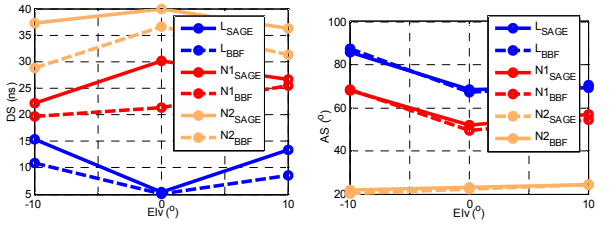


Figure 5. DS and AS of indoor environment

Figure 5 depicts the delay spread (DS) and angular spread (AS) calculated from the multipath components founded by BBF and SAGE, respectively. Table 2 shows the average standard deviation (STD) between BBF and SAGE for each AS and DS. The STD of AS between the two algorithms is observed to be relatively small (approximately within 2 degree). On the other hand, with respect to DS, we got a standard deviation having a range from 3 to 6 ns.

TABLE 2. STD DEVIATION BETWEEN BBF AND SAGE

|      | AS STD (°) | DS STD (ns) |
|------|------------|-------------|
| LOS  | 1.39       | 3.84        |
| NLOS | 1.40       | 5.65        |

TABLE 3. COMPLEXITY ANALYSIS OF BBF AND SAGE

| SAGE;<br>Iteration<br>Number<br>(I) | SAGE;<br>Number<br>of Path<br>(L) | SAGE;<br>Computing<br>Time<br>[second] | BBF;<br>Computing<br>Time<br>[second] | Saving<br>time by<br>BBF<br>[%] |
|-------------------------------------|-----------------------------------|----------------------------------------|---------------------------------------|---------------------------------|
| 3                                   | 100                               | 3,793                                  | 20.5                                  | 99.46                           |
| 3                                   | 200                               | 6,506                                  |                                       | 99.68                           |
| 5                                   | 100                               | 6,257                                  |                                       | 99.67                           |
| 5                                   | 200                               | 11,810                                 |                                       | 99.83                           |

We simulate the computation time of both BBF and SAGE to compare and understand the complexity of each algorithm. It should be noted that the iterative algorithms such as SAGE are complicated to count algorithm complexity. Therefore, we executed the simulation of SAGE depending on two key variables such as total iteration number ( $I$ ) and total number of

path ( $L$ ) (see Section II). For fair comparison, the computing time of SAGE and BBF was respectively calculated based on one measurement sample. For the BBF, the processing time was approximately 20 seconds. Table 3 lists our simulation results for each algorithm. It is noted that both algorithms were run in MATLAB. In terms of computational complexity, our simulation results show that BBF can save almost 99% computation time comparing to the SAGE.

## V. CONCLUSIONS

In this paper, we investigate the performance of SAGE and BBF using measurement data at office environment in the 28 GHz frequency band. The performance was evaluated through observation of two parameters such as standard deviation of large scale parameters and complexity of each algorithm. Our simulation results show that the BBF can save the computing time a lot compared to SAGE. Furthermore, the value of AS from BBF was similar with SAGE. In terms of DS, the two algorithms have somewhat a little difference results within 6 ns. Hence, for understanding the multipath propagation characteristics e.g. angular spread and delay spread within a tolerable error range, the use of Bartlett Beamformer seems attractive since it has comparatively small computing time. However, to develop a channel model through more accurate parameterization of multipath components, it is still believed that the use of high-resolution estimation algorithms is more appropriate.

## ACKNOWLEDGMENT

This work was supported by Institute for Information & communications Technology Promotion (IITP) grant funded by the Korea government (MSIP) [B0101-15-222, Development of core technologies to improve spectral efficiency for mobile big-bang]

## REFERENCES

- [1] B. Fleury, M. Tschudin, R. Heddergott, D. Dahlhaus, and K. Ingeman Pedersen, "Channel Parameter Estimation in Mobile Radio Environments Using the SAGE Algorithm", *IEEE Journal on Selected Areas in Communications*, vol. 17, no. 3, pp. 434-450, 1999.
- [2] R. O. Schmidt, "Multiple emitter location and signal parameter estimation," *IEEE Trans. Antennas Propagat.*, vol. AP-34, pp. 276-280, Mar. 1986.
- [3] A. Richter and R. S. Thoma, "Joint maximum likelihood estimation of specular paths and distributed diffuse scattering," in *Proc. IEEE VTC—Spring*, Jun. 2005, vol. 1, pp. 11-15.
- [4] M. Kim, J. Lee, J. Liang, J. Kim "Multipath Channel Characteristics for Propagation between Mobile Terminals in Urban Street Canyon Environments", the *17th International Conference on Advanced Communication Technology (ICACT)*, pp. 511 – 516.
- [5] J. Liang, M. Kim, J. Lee, "A geometrical approach for multipath characteristics study with 2.8 GHz measurements", the *17th International Conference on Advanced Communication Technology (ICACT)*, pp. 427-430.
- [6] M. Bartlett, "Smoothing periodograms from time series with continuous spectra," *Nature*, vol. 161, 1948.



next generation mobile communications.

**Jinyi Liang** (BS'04–MS'13) is a Researcher in the Advanced Communications Research Laboratory at Electronics and Telecommunications Research Institute (ETRI). He is Chinese and joined ETRI, Daejeon, Rep. of Korea, in July 2013, and he's working on the project 'Wireless Channel and Frequency Characterization based on Field Measurements for Broadband Mobile Hot-Spot Applications'. His research interests include MIMO, channel measurement and channel modeling for



of MIMO channels. His research interests include MIMO, channel measurement and channel modeling for next generation mobile communications.

**Myung-Don Kim** (BS'93–MS'95) is a Principal Researcher in the Advanced Communications Research Laboratory at Electronics and Telecommunications Research Institute (ETRI). He joined ETRI, Daejeon, Rep. of Korea, in 1995, and he worked on the development of mobile test-beds for CDMA, IMT-2000 and WCDMA systems. Since 2006, he has been involved in the development of wideband MIMO channel measuring system, measurement and channel estimation



allocations, device-to-device communication.

**Juyul Lee** (BS'96–MS'98–PhD'10) is a Senior Researcher in the Advanced Communications Research Laboratory at Electronics and Telecommunications Research Institute (ETRI) since 2000. Prior joining with ETRI, he was a Research Engineer with the Agency for Defense Development (ADD) from 1998 to 2000. His research spans the fields of information theory and wireless communications, with special interests in multiple-antenna/multiple-user/multi-cell resource



channel modeling for multilink and mobile-to-mobile systems and millimeter-wave wireless communications.

**Jae-Joon Park** received his BS and MS in control and instrumentation from Chungang University, Seoul, Rep. of Korea, in 1997 and 1999, respectively. Since 1999, he has been a senior researcher at ETRI, Daejeon, Rep. of Korea. He has worked on development of smart antennas for FDD/TDD WCDMA systems, the wireless broadband (WiBro) system, and a wideband wireless channel model for next-generation mobile communication. His research interests are wireless



Institute (ETRI), and he is also working toward the PhD degree from KAIST Daejeon, Korea. His main research interests include UWB RF transceiver front-end circuit design and system-level integration of transceivers. He is also interested in 5G mobile RF system, Power amplifier and RFIC.

**Bonghyuk Park** received the BS degree in electrical engineering from Kyungpook National University, Korea, in 1996, and the MS degree in mechatronics from Gwangju Institute Science and Technology (GIST), Gwangju, Korea, in 1998, respectively. From 1998 to 1999, he worked as an RF Application Engineer at Ansoft. Since 1999, he has been with Electronics and Telecommunications Research