Joint channel and data estimation for time hopping-ultrawide bandwidth multiple access system in multipath channel

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Abstract — *We consider a proper detection schemes for time hopping (TH)-ultra wide bandwidth (UWB) multiple access (MA) systems in multipath channel. First, we apply the well-known minimum mean square error (MMSE) multiuser detector (MUD). Next, we propose the improved detection scheme, which has a low complexity and can jointly estimate the channel parameter. Simulation results show that the proposed scheme shows a good performance with a low complexity and can estimate the channel parameter more correctly than the conventional scheme.*[1]

Index Terms — channel estimation, low complexity, MUD, TH-UWB.

I. INTRODUCTION

ULTRAWIDE bandwidth (UWB) technique has attracted interest as one of solutions for high capacity short range indoor systems, because of its robustness in dense multipath environment, low cost, low power implementation, and the high bit rate achievable.

The short range high data rate applications such as WPAN require that multiple transmitters coexist inside office and residential buildings where the indoor wireless channel introduces a dense multiple environment. Therefore, there is a need for proper systems to separate multiple users in wireless indoor channel. For this, Time hopping (TH)-UWB and direct sequence (DS)-UWB system have been proposed. TH-UWB system uses TH sequence for distinguishing multiuser whereas DS-UWB pseudo noise (PN) sequence. TH-UWB system is more robust in multipath environment than DS-UWB system because TH-UWB system transmits pulses discretely. In this paper, we consider TH-UWB system.

For TH-UWB system, various detection schemes have been investigated so far. The representative methods are the matched filter [1], rake and autocorrelation receiver [2]. [1] includes performance analysis of the receiver in the multiuser environment without considering the multipath environment whereas [2] in the multipath environment without considering multiuser. As in those works, in considering both multipath and multiuser, the proper detection scheme was not proposed. Additionally, the channel parameter must be correctly estimated for a favorable performance. Therefore, in this paper, we design the detector for multiuser interference (MUI) suppression in multipath channel. We apply the well-known minimum mean square error (MMSE) multiuser detector (MUD) and propose the improved scheme for considering problems of MMSE MUD. The proposed scheme does blind MUD with a low complexity and then, estimates the channel parameter more correctly than [3].

The rest of this paper is follows. The modified transmitted signal model is presented in section II. Section III and IV describe MMSE MUD and the proposed scheme, respectively. Section V presents simulation results and section VI brief conclusion.

II. SYSTEM MODEL

Since the conventional detectors [1], [2] for TH-UWB need sampling per frame duration but MUD requires sampling per chip duration, the conventional model is difficult to represent the sample value per chip duration in MUD. Therefore, in this paper, the conventional transmitted signal model of *k*th user $s^{(k)}(t)$ is modified as follows

$$s^{(k)}(t)=\sqrt{P^{(k)}}\sum_{i=0}^{\infty}(-1)^{b^{(k)}(i)}\sum_{j=0}^{N_f-1} p_j^{(k)}w(t-iT_b-jT_f-c_j^{(k)}T) \tag{1}$$

where $P^{(k)}$ is the signal power of *k*th user, $b^{(k)}(i)$ is *i*th bit of *k*th user, $p_j^{(k)}$ and $c_j^{(k)}$ represent the frame sequence and TH sequence for *j*th frame of *k*th user, respectively, $w(t)$ is the UWB pulse with pulse width T_w. N_f and N_c represent the number of frames consisting of one bit and chips consisting one frame, respectively. Additionally, T_b, T_f and T_c are bit, frame and chip duration, respectively. The TH sequence $c_j^{(k)}$, $0\leq j<N_f-1$ provides additional shift in multiple of the chip duration T_c, for multiple access. In this paper, TH sequence is modeled as an independent random variable with the value of $0\leq c^{(k)}_j<N_h$. Each bit with PSK modulation is transmitted using N_f consecutive pulses, leading to a $(N_f,1)$ repetition code. The resulting bit duration is thus $T_b=N_fT_f$. The frame duration is assumed to be an integer multiple of chip duration, that is $T_f=N_cT_c$ where N_c is the number of chips in one frame. Hereby, the chip duration is assumed to be equal to pulse width. Finally the chip sequence $s_j^{(k)}$ is defined as follows

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Fig. 1 MMSE MUD receiver

$$s_i^{(k)} = \begin{cases} p_j^{(k)} & if \quad i = jN_c + c_j^{(k)} \\ 0 & otherwise \end{cases} \tag{2}$$

Due to sampling per chip duration, it is possible that multipath channel $h^{(k)}(t)$ is modeled as the FIR (Finite Impulse Response) with tap spacing of T_c.

$$h^{(k)}(t) = \sum_{i=0}^{L-1} h_i^{(k)} \delta(t - iT_c) \tag{3}$$

where $h_i^{(k)}$ is channel gain, and L is the number of paths.

Furthermore, a frame duration is chosen to be sufficiently large, which is $N_h+L-1 \leq N_c$ to avoid interpulse interference (IPI).

III. MMSE MUD

It is known that MMSE MUD features the best performance of linear detectors [5]. Fig. 1 shows MMSE MUD receiver for TH-UWB MA system in multipath channel.

The received signal vector composed of $N_cN_f$sample values for ith bit, **r(i)** is

$$\begin{aligned} \mathbf{r(i)} &= [r_0(i)\ r_1(i)\ \cdots\ r_{N_cN_f-1}] \\ &= \sqrt{P^{(1)}} d^{(1)}(i) \mathbf{H}^{(1)} \mathbf{s}^{(1)} \\ &\quad + \sum_{k=2}^{N_u} \sqrt{P^{(k)}} \{ d^{(k)}(i-1) \mathbf{v^{(k)}} + d^{(k)}(i) \mathbf{g^{(k)}} \} \\ &\quad + \mathbf{n(i)} \end{aligned} \tag{4}$$

where $r_j(i)$ is the sample value for $(j+1)$th chip of ith bit, $d^{(k)}(i)=(-1)^{b(k)(i)}$, $\mathbf{H^{(k)}}$ is the channel information matrix, $\mathbf{s^{(k)}}=[s_0(k)\ s_1(k)\ \cdots\ s_{NcNf-1}(k)]$ is the chip sequence vector of kth user, $\mathbf{g^{(k)}}=[g_0(k)\ g_1(k)\ \cdots\ g_{NcNf-1}(k)]$ is the interference vector by ith bit of kth user, $\mathbf{v(k)}=[v_0(k)\ v_1(k)\ \cdots\ v_{NcNf-1}(k)]$ is the interference vector by $(i-1)$th bit of kth user and $\mathbf{n^{(k)}}=[n_0(k)\ n_1(k)\ \cdots\ n_{NcNf-1}(k)]$ represents additive white gaussian noise (AWGN). The detailed expression is described in Appendix 1.

When the filter vector is represented by **f** and it is assumed that the first user is desired user, MMSE filter vector is

$$\begin{aligned} \mathbf{f_{MMSE}} &= \arg\min_{\mathbf{f}} E[|d^{(1)}(i) - \mathbf{f^T r(i)}|^2] \\ &= \mathbf{R_r^{-1} H^{(1)} s^{(1)}} \end{aligned} \tag{5}$$

where $\mathbf{R_r}=E[\mathbf{r(i)r^T(i)}]$ is the autocorrelation matrix of the received signal vector.

MMSE MUD is optimal in a sense of minimizing mean square error. However, channel information is needed for MUD and it has the high complexity in computing the inverse of autocorrelation matrix. Therefore we propose the detector having good the performance with a low complexity in section IV.

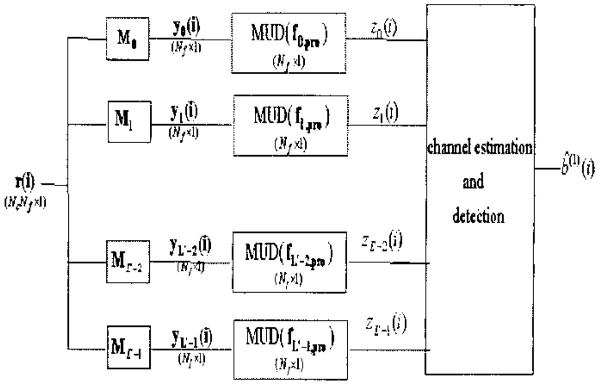

Fig. 2 The receiver structure of the proposed scheme

IV. THE PROPOSED SCHEME

Fig. 2 shows the structure of the proposed MUD. It is applicable to only TH-UWB system with guard interval for avoiding interpulse interference (IPI).

For selecting only the jth path of the first user, **r(i)** is multiplied by the selection matrix for jth path $\mathbf{M_j}$, $0 \leq j < L' \leq L$ (see Appendix 2). Each received signal vector $\mathbf{y_j(i)}$ $0 \leq j < L'$ is

$$\begin{aligned} \mathbf{y_j(i)} &= \mathbf{M_j r(i)} \\ &= \sqrt{P^{(1)}} d^{(1)}(i) \mathbf{M_j H^{(1)} s^{(1)}} \\ &\quad + \sum_{k=2}^{N_u} \sqrt{P^{(k)}} \mathbf{M_j} \{ d^{(k)}(i-1) \mathbf{v^{(k)}} + d^{(k)}(i) \mathbf{g^{(k)}} \} \\ &\quad + \mathbf{M_j n(i)} \end{aligned} \tag{6}$$

In (7), the first part represents the jth path signal of the first user, the second part the interference by other user and the third part AWGN.

Each received signal vector $\mathbf{y_j(i)}$ is passed by N_fx 1 filter $\mathbf{f_{j,pro}}$. The jth filter output for the ith bit of the first user $z_j(i)$ is $\mathbf{f_j^T y_j(i)}$. The average $SINR$ of jth filter output, $SINR_j$ is

$$SINR_j = \frac{P^{(1)} |h_j^{(1)}|^2 \mathbf{f_j^T p^{(1)} p^{(1)T} f_j}}{\mathbf{f_j^T R_{y_j(i)} f_j} - P^{(1)} |h_j^{(1)}|^2 \mathbf{f_j^T p^{(1)} p^{(1)T} f_j}} \tag{7}$$

Based on (7), for reducing MUI without the channel information, the filter is designed with maximizing SINR. Therefore the filter $\mathbf{f_{j,pro}}$ maximizing jth filter output is

$$\mathbf{f_{j,pro}} = \arg\max_{\mathbf{f_j}} SINR_j = \mathbf{R_{y_j(i)}^{-1} p^{(1)}} \tag{8}$$

where $\mathbf{R_{yj(i)}}$ is autocorrelation matrix of $\mathbf{y_j(i)}$ (see Appendix 3).

For channel estimation by exploiting L' filter outputs, the least square estimate method proposed in DS-CDMA system is applied [4]. This method used after eliminating the interference is efficient because it shows the performance near optimum in high SNR and it's complexity is lower than any other blind methods. The vector **z(i)** is defined as follows

$$\mathbf{z(i)} = [\ \frac{z_0(i)}{\mathbf{f}_{\mathbf{0,pro}}^{\mathbf{T}}\mathbf{p}^{(1)}}\ \ \frac{z_1(i)}{\mathbf{f}_{\mathbf{1,pro}}^{\mathbf{T}}\mathbf{p}^{(1)}}\ \ \cdots\ \ \frac{z_{L'-1}(i)}{\mathbf{f}_{\mathbf{L-1,pro}}^{\mathbf{T}}\mathbf{p}^{(1)}}]^T \tag{9}$$

$$= \sqrt{P^{(1)}}d^{(1)}(i)\mathbf{h}^{(1)} + \mathbf{I}'_{\mathbf{MUI}}\mathbf{(i)} + \mathbf{n}'\mathbf{(i)}$$

where $\mathbf{h}^{(1)}=[h_0^{'(1)} \cdots h_{L'-1}^{(1)}]$ is a channel vector of the first user , $\mathbf{I}'_{\mathbf{MUI}}\mathbf{(i)}$ represents the normalized MUI, $\mathbf{n}'\mathbf{(i)}$ the normalized AWGN. Because $\mathbf{I}'_{\mathbf{MUI}}\mathbf{(i)}$ is very lower than the signal power of the first user (below 10dB in result of the simulation), (9) is approximated as follows

$$\mathbf{z(i)} \approx \sqrt{P^{(1)}}d^{(1)}(i)\mathbf{h}^{(1)} + \mathbf{n}'\mathbf{(i)} \tag{10}$$

By approximation, the channel parameter $\mathrm{h}^{(1)}$ can be estimated simply by the method described in [4]. The estimated channel vector $\hat{\mathrm{h}}^{(1)}$ is

$$\hat{\mathbf{h}}^{(1)} = \text{principle eigenvector of } \overset{\square}{\mathbf{R}}_{\mathbf{z(i)}}$$

$$\text{where } \overset{\square}{\mathbf{R}}_{\mathbf{z(i)}} = \frac{1}{i+1}\sum_{j=0}^{i}\mathbf{z(j)z(j)}^{\mathbf{T}} \tag{11}$$

Based on the estimated channel information, the bit is detected by combining filter outputs. In the case of MMSE combining, a bit is detected as follows

$$\hat{b}^{(1)}(i) = \begin{cases} 0 & \text{if} \quad (\mathbf{R}_{\mathbf{z(i)}}^{-1}\hat{\mathbf{h}}^{(1)})^{\mathbf{T}}\mathbf{z(i)} > 0 \\ 1 & \text{if} \quad (\mathbf{R}_{\mathbf{z(i)}}^{-1}\hat{\mathbf{h}}^{(1)})^{\mathbf{T}}\mathbf{z(i)} < 0 \end{cases} \tag{12}$$

In the case of MRC combining,

$$\hat{b}^{(1)}(i) = \begin{cases} 0 & \text{if} \quad \hat{\mathbf{h}}^{(1)^{\mathbf{T}}}\mathbf{z(i)} > 0 \\ 1 & \text{if} \quad \hat{\mathbf{h}}^{(1)^{\mathbf{T}}}\mathbf{z(i)} < 0 \end{cases} \tag{13}$$

MRC combining compensates only channel information whereas MMSE combining additionally reduces the residual interference. Therefore the performance of MMSE combining is better.

V. PERFORMANCE ANAYSIS

A. Output SINR

Output signal to interference and noise ratio (*SINR*) is defined as follow

$$\begin{aligned} &Output\ \ SINR \\ &= the\ first\ user's\ power\ / \\ &\quad (the\ other\ users'\ power + the\ AWGN\ power) \end{aligned} \tag{14}$$

Based on (14), output *SINR* of the discussed MUD is computed. First, output *SINR* of MMSE MUD, $SINR_{MMSE}$ is

$$SINR_{MMSE} = \frac{P^{(1)}(\mathbf{H}^{(1)}\mathbf{s}^{(1)})^{\mathbf{T}}\mathbf{R}_{\mathbf{r(i)}}^{-1}(\mathbf{H}^{(1)}\mathbf{s}^{(1)})}{1 - P^{(1)}(\mathbf{H}^{(1)}\mathbf{s}^{(1)})^{\mathbf{T}}\mathbf{R}_{\mathbf{r(i)}}^{-1}(\mathbf{H}^{(1)}\mathbf{s}^{(1)})} \tag{15}$$

Next, output *SINR* of the proposed scheme in the case of MRC combining, $SINR_{PRO(MRC)}$ is

$$SINR_{PRO(MRC)} = \frac{P^{(1)}\hat{\mathbf{h}}^{(1)^{\mathbf{T}}}\mathbf{h}^{(1)}\mathbf{h}^{(1)^{\mathbf{T}}}\hat{\mathbf{h}}^{(1)}}{\hat{\mathbf{h}}^{(1)^{\mathbf{T}}}\mathbf{R}_{\mathbf{z(i)}}\hat{\mathbf{h}}^{(1)} - P^{(1)}\hat{\mathbf{h}}^{(1)^{\mathbf{T}}}\mathbf{h}^{(1)}\mathbf{h}^{(1)^{\mathbf{T}}}\hat{\mathbf{h}}^{(1)}} \tag{16}$$

Finally, in the case of MMSE, $SINR_{PRO(MMSE)}$ is

$$SINR_{PRO(MMSE)} = \frac{P^{(1)}\hat{\mathbf{h}}^{(1)^{\mathbf{T}}}\mathbf{R}_{\mathbf{z}}^{-1}\hat{\mathbf{h}}^{(1)}}{1 - P^{(1)}\hat{\mathbf{h}}^{(1)^{\mathbf{T}}}\mathbf{R}_{\mathbf{z}}^{-1}\hat{\mathbf{h}}^{(1)}} \tag{17}$$

With (15), (16) and (17), the comparison of the performance for the discussed MUD is attained through the simulation.

B. The comparison of the complexity for MUD

The complexity for each MUD is dominated by matrix inversion. In computing the inversion matrix of the (NxN) matrix, the multiplication complexity of $O(N^3)$ is required. Therefore the complexity for each MUD is as follow

For MMSE MUD, the complexity is

$$O((N_c N_f)^3) \tag{18}$$

For the proposed scheme in the case of MRC combing,, the complexity is

$$L' \times O(N_f^3) \tag{19}$$

For the proposed scheme in the case of MRC combing, the complexity is

$$L' \times O(N_f^3) + O(L'^3) \tag{20}$$

The value of $N_c N_f$ is actually in the range of several hundreds to thousands and the value of N_f several tens to several hundreds. Therefore, MMSE MUD is difficult to be realized due to very high complexity whereas the proposed scheme is possible to be realized with very lower complexity than MMSE MUD. In case of the proposed scheme, the complexity for MMSE combining is similar to that for MRC combining since L' is gernerally less than N_f.

C. The simulation results

In simulation, the transmitted pulses use Gaussian pulse of 1ns duration. Multipath channel uses cm1 channel model on final report of IEEE 802.15.3a [5] and N_c=20, N_h=6, L=20, N_f=30. The chip duration is equal to the pulse duration.

In Fig, 3 and 4, the number of multiuser is 40, L'=16, and near-far (15dB) environment is considered.

Fig.3 shows output SINR of various detectors in multiuser and multipath environment. The matched filter and the rake receiver in the case of MRC combining show very poor performance and they seem to be impossible to be used in multipath and multiuser environment. The rake receiver in case of MMSE combining is better than previous detectors, but can't get the *SINR* over 10dB. In comparison, the proposed scheme shows a good performance with low complexity.

Fig. 4 shows mean square channel estimation error. Because of estimating the channel parameter after reducing MUI, the proposed scheme shows very smaller estimation error than the conventional scheme.

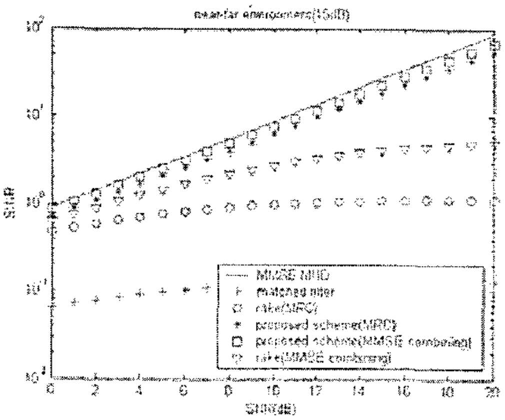

Fig. 3 Output *SINR* of various detectors vs *SNR*

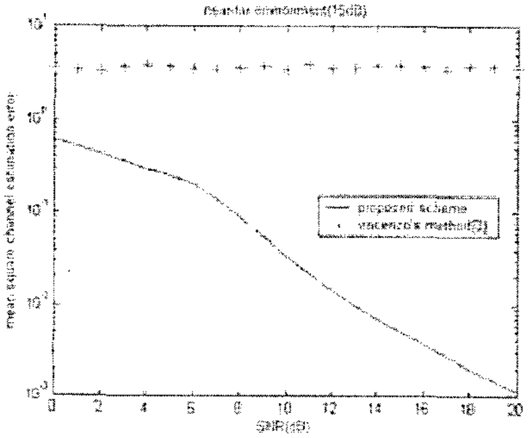

Fig. 4 mean square channel estimation error vs SNR

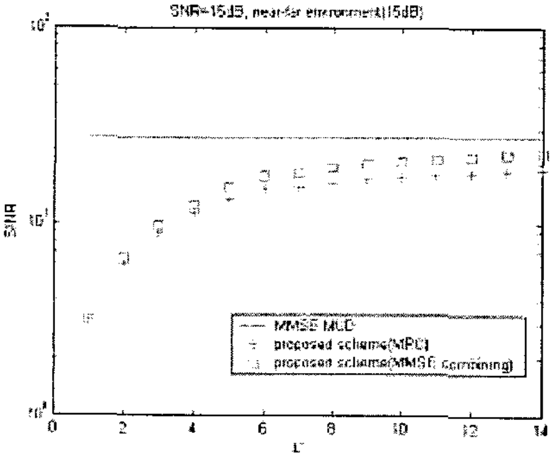

Fig. 5 Output SINR of the proposed scheme as varying *L'*

Fig 5 shows SINR of the proposed scheme with varying L'. In considering trade-off between the complexity and performance, $L' = 5$ or 6 is appropriate. Because this value corresponds to root mean square (rms) delay of cm1 channel, it is appropriate that L' is selected by rms delay of multipath channel.

VI. CONCLUSION

The conventional detectors for TH-UWB system are not appropriate in multipath and multiuser environment due to the serious performance degradation.

We present a proper detection scheme for TH-UWB MA system in multipath channel. First we apply the well-known MMSE MUD. Then, we propose an improved detection scheme, which has low complexity and can jointly estimate channel parameter. The proposed scheme shows good performance with low complexity and can estimate channel parameter more correctly than conventional scheme. In addition, in considering trade-off between performance and complexity, it is appropriate that the number of fingers in the proposed scheme is selected by the rms delay of multipath channel.

APPENDIX

A. Appendix 1

$$H_{i,j}^{(k)} = \begin{cases} h_{i-j}^{(k)} & if \quad i = jN_c + c_j^{(k)} \\ 0 & otherwise \end{cases} \tag{21}$$

$$v_j^{(k)} = \begin{cases} 0, & if \quad 0 \le j < j_o^{(k)} \\ \breve{s}_{j-j_o^{(k)}}^{(k)} \rho(u_k) & if \quad j = j_0^{(k)} \\ \breve{s}_{j-j_o^{(k)}-1}^{(k)} \rho(T_c - u_k) + \tilde{s}_{j-j_o^{(k)}}^{(k)} \rho(u_k) & \\ \quad if \quad j_o^{(k)} < j < N_c N_f - 1 & \end{cases} \tag{22}$$

$$g_j^{(k)} = \begin{cases} \breve{s}_{j-j_o^{(k)}+N_s N_f}^{(k)} \rho(u_k) + \tilde{s}_{j-j_o^{(k)}+N_s N_f-1}^{(k)} \rho(T_c - u_k), & \\ \quad if \quad 0 \le j < j_o^{(k)} & \\ \breve{s}_{j-j_o^{(k)}+N_s N_f-1}^{(k)} \rho(T_c - u_k), & \text{if} \quad j = j_0^{(k)} \\ 0, & \text{if} \quad j_o^{(k)} < j < N_c N_f - 1 \end{cases} \tag{23}$$

where the delay τ_k for k=1, …,N_u associated to each user in an asynchronous multiple access system is assumed as follows $\tau_k = j_0^{(k)} T_c + u^{(k)}$, $0 \le u^{(k)} < T_c$, $0 \le j_0^{(k)} < N_c N_f$]. And $\check{s} = \mathbf{H}^{(k)} \mathbf{s}^{(k)} = [\check{s}_0^{(k)} \cdots \check{s}_{NcNf-1}]$. Finally, $\rho(x)$ is

$$\rho(x) = \int_{-\infty}^{\infty} w(t-x) w(t) dt$$

$$n_j(i) = \int_{-\infty}^{\infty} n(t)w(t - iT_b - jT_c)dt, \quad 0 \le j < N_c N_f \quad (24)$$

B. Appendix 2

For $1 \le i < N_f$, $1 \le j < L-1$

$$\mathbf{M}_{0i,k} = \begin{cases} s_{(i-1)N_c+j} & if \quad (i-1)N_c + 1 \le k < iN_c \\ 0 & otherwise \end{cases} \quad (25)$$

$$\mathbf{M}_\mathrm{j} = \mathbf{M}_\mathrm{j-1} \begin{bmatrix} 0 & & & & & 1 \\ 1 & 0 & & 0 & & 0 \\ & 1 & 0 & & & 0 \\ & & 1 & \ddots & & \vdots \\ & 0 & & \ddots & 0 & \\ & & & & 1 & 0 \end{bmatrix}, 1 \le \mathrm{j} \le \mathrm{L\text{-}1} \quad (26)$$

C. Appendix 3

$$\mathbf{f}_\mathbf{j,pro} = \arg\max_{\mathbf{f}_\mathrm{j}} SINR_j \quad (27)$$

When putting (11) into $SINR_j$

$$\begin{aligned} \mathbf{f}_\mathbf{j,pro} &= \arg\min_{\mathbf{f}_\mathrm{j}} \{ \frac{\mathbf{f}_\mathbf{j}^\mathbf{T} \mathbf{R}_{\mathbf{y}_\mathbf{j}(\mathbf{i})} \mathbf{f}_\mathbf{j}}{P^{(1)} |h_j|^2 \mathbf{f}_\mathbf{j}^\mathbf{T} \mathbf{p}^{(1)} \mathbf{p}^{(1)^\mathbf{T}} \mathbf{f}_\mathbf{j}} - 1 \} \\ &= \arg\min_{\mathbf{f}_\mathrm{j}} \frac{\mathbf{f}_\mathbf{j}^\mathbf{T} \mathbf{R}_{\mathbf{y}_\mathbf{j}(\mathbf{i})} \mathbf{f}_\mathbf{j}}{\mathbf{f}_\mathbf{j}^\mathbf{T} \mathbf{p}^{(1)} \mathbf{p}^{(1)^\mathbf{T}} \mathbf{f}_\mathbf{j}} \end{aligned} \quad (28)$$

After $\mathbf{R}_{\mathbf{yj(i)}} = \mathbf{L}^\mathbf{T}\mathbf{L}$ and $\mathbf{v} = \mathbf{L}\mathbf{f}_\mathrm{j}$ are defined, put them into (28)

$$\begin{aligned} \mathbf{v}_\mathbf{j,pro} &= \arg\min_{\mathbf{v}} \frac{\mathbf{v}^\mathbf{T}\mathbf{v}}{\mathbf{v}^\mathbf{T} \mathbf{L}^{-\mathbf{T}} \mathbf{p}^{(1)} \mathbf{p}^{(1)^\mathbf{T}} \mathbf{L}^{-1} \mathbf{v}} \\ &= \mathbf{L}^{-\mathbf{T}} \mathbf{p}^{(1)} = \mathbf{L}\mathbf{f}_\mathbf{j,pro} \end{aligned} \quad (29)$$

Therefore,

$$\begin{aligned} \mathbf{f}_\mathbf{j,pro} &= \arg\max_{\mathbf{f}_\mathrm{j}} SINR_j = (\mathbf{L}^\mathbf{T}\mathbf{L})^{-1} \mathbf{p}^{(1)} \\ &= \mathbf{R}_{\mathbf{y}_\mathbf{j}(\mathbf{i})}^{-1} \mathbf{p}^{(1)} \end{aligned} \quad (30)$$

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