Narrowband Channel Estimation for Hybrid Beamforming Millimeter Wave Communication Systems with One-Bit Quantization

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Motivation (I)

Why hybrid beamforming systems with low-resolution ADCs?

- Propagation losses are high in millimeter wave bands
- Large-scale antenna arrays are needed to compensate the losses
- High-speed ADCs with high resolution are power-demanding

➔ We reduce power consumption by using a ***hybrid beamforming architecture*** and ***low-resolution quantizers***

Channel estimation is challenging

- Conventional algorithms need significant training overhead
- Hybrid beamformers give only indirect access to channels
- Low-resolution ADCs distort training signals

➔ We propose a ***compressed sensing*** algorithm

Generalized Approximate Message Passing (GAMP)

- Compressed sensing for nonlinear observations of a sparse signal

➔ We modify ***one-bit GAMP*** for channel estimation which outperforms other variants of GAMP & least squares channel estimator

Modified One-Bit GAMP (III)

Algorithm 1 One-bit GAMP

Initialize:

$t=0,\ \hat{\mathbf{h}}_{\mathrm{v}}^t=\mathbb{E}[\mathbf{h}_{\mathrm{v}}],\ \mathbf{v}_{\mathbf{h}_{\mathrm{v}}}^t=\mathrm{Var}[\mathbf{h}_{\mathrm{v}}],\ \hat{\mathbf{s}}^t=0,$

for $t=1,\cdots,T$ **do**

Measurement update:

$\mathbf{v}_p^{t+1}=(\mathbf{W}\bullet\mathbf{W})\mathbf{v}_{\mathbf{h}_{\mathrm{v}}}^t,$

$\hat{\mathbf{p}}^{t+1}=\mathbf{W}\mathbf{h}_{\mathrm{v}}^t-\mathbf{v}_p^{t+1}\bullet\hat{\mathbf{s}}^t,$

for all i **do**

$\left[\hat{\mathbf{s}}^{t+1}\right]_i=\frac{1}{[\mathbf{v}_p^{t+1}]_i+\sigma_{\tilde{n}}^2}\left(\mathbb{E}\left[r|r\in Q^{-1}([\mathbf{y}]_i)\right]-[\hat{\mathbf{p}}^{t+1}]_i\right),$

$\left[\mathbf{v}_s^{t+1}\right]_i=\frac{1}{[\mathbf{v}_p^{t+1}]_i+\sigma_{\tilde{n}}^2}\left(1-\frac{\mathrm{Var}\left[r|r\in Q^{-1}([\mathbf{y}]_i)\right]}{[\mathbf{v}_p^{t+1}]_i+\sigma_{\tilde{n}}^2}\right),$

end for

Estimation update:

$\mathbf{v}_r^{t+1}=\left((\mathbf{W}\bullet\mathbf{W})^{\mathsf{T}}\mathbf{v}_s^{t+1}\right)^{-1},$

$\hat{\mathbf{r}}^{t+1}=\hat{\mathbf{h}}_{\mathrm{v}}^t+\mathbf{v}_r^{t+1}\bullet\left(\mathbf{W}^{\mathsf{T}}\hat{\mathbf{s}}^{t+1}\right),$

for all i **do**

$\left[\hat{\mathbf{h}}_{\mathrm{v}}^{t+1}\right]_i=\mathbb{E}\left[h_{\mathrm{v}}|[\hat{\mathbf{r}}^{t+1}]_i\right],$

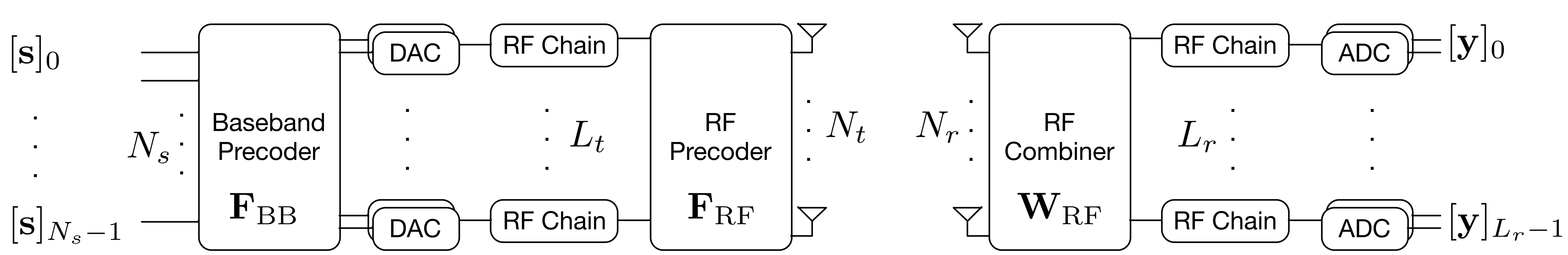
$\left[\mathbf{v}_{\mathbf{h}_{\mathrm{v}}}^{t+1}\right]_i=\mathrm{Var}\left[h_{\mathrm{v}}|[\hat{\mathbf{r}}^{t+1}]_i\right],$

end for

end for

Modification (the $\sigma_{\tilde{n}}^2$ terms in lines 6 and 7)

System & Channel Models (II)



Geometric Channel Model

$$\mathbf{H}=\sqrt{\frac{N_rN_t}{N_p}}\sum_{l=0}^{N_p-1}\alpha_l\mathbf{a}_{\mathrm{r}}(\theta_{rl})\mathbf{a}_{\mathrm{t}}^{\mathsf{H}}(\theta_{tl})$$

Receive and transmit array response vectors; Channel path gain

Discrete Time Received Signal

$$\mathbf{y}_m=\mathrm{Q}\left(\sqrt{\rho}\mathbf{W}_{\mathrm{RF},m}^{\mathsf{H}}\mathbf{H}\mathbf{F}_{\mathrm{RF},m}\mathbf{F}_{\mathrm{BB},m}\mathbf{s}_m+\mathbf{W}_{\mathrm{RF},m}^{\mathsf{H}}\mathbf{n}_m\right)$$

Signal power; Noise; Quantization

Sparse Recovery Formulation

$$\mathbf{y}=\left[\mathbf{y}_0^{\mathsf{T}},\mathbf{y}_1^{\mathsf{T}},\cdots,\mathbf{y}_{M-1}^{\mathsf{T}}\right]^{\mathsf{T}}=\mathrm{Q}\left(\sqrt{\rho}\mathbf{\Phi}\mathbf{\Psi}\mathbf{h}_{\mathrm{v}}+\mathbf{n}\right)$$

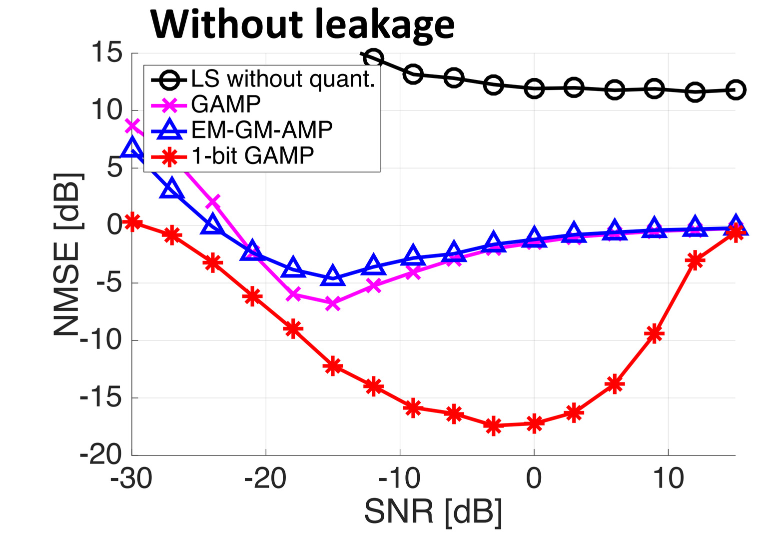
Sensing matrix; Dictionary; Sparse channel vector

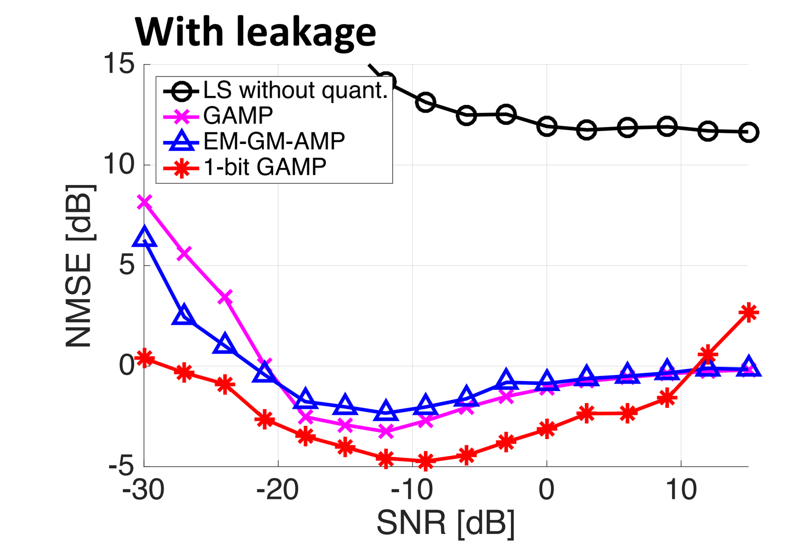
Simulation Details

- *64 Tx ant., 16 Rx ant.*
- *4 Tx and Rx RF chains*
- *2 channel paths*
- *64 frames*
- Baseband simulation
- GAMP, EM-GM-GAMP and LSE evaluated
- 1-bit resolution ADCs
- NMSE used as performance metric

$$\mathrm{NMSE}=\mathbb{E}\left[\|\mathbf{H}-\hat{\mathbf{H}}\|_F^2/\|\mathbf{H}\|_F^2\right]$$

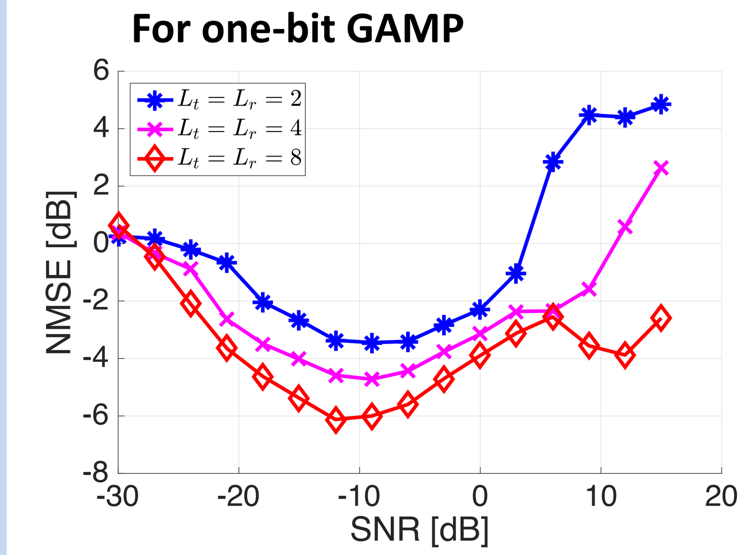
Numerical Results (IV)

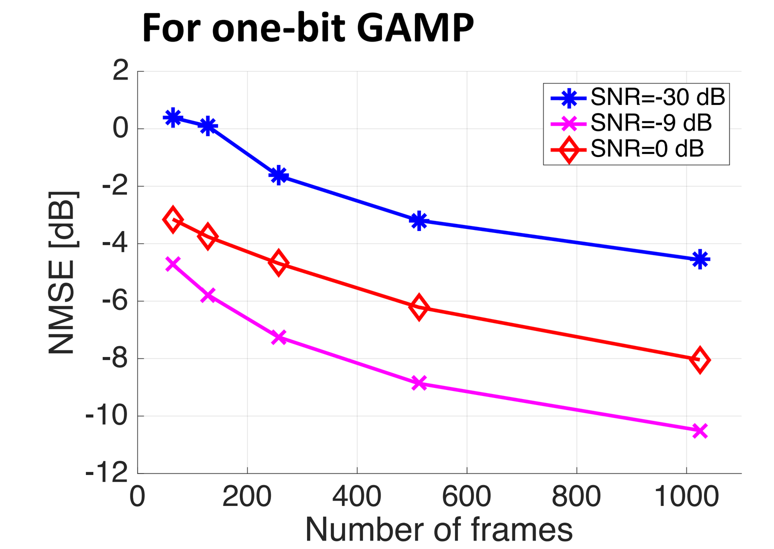




One-bit GAMP vs. Others

- One-bit GAMP outperforms with or without leakage effects
- Leakage degrades performance of all algorithms
- Conventional LSE performs far worse than GAMP variants
- Higher SNR does not necessarily yield better performance





NMSE vs. Number of RF chains

- More RF chains improve performance across the SNR range

NMSE vs. Number of Frames

- More frames decrease channel estimation errors
- Best performance is obtained with -9 dB SNR

Conclusion (V)

- **Proposed a modified one-bit GAMP for channel estimation for hybrid beamforming systems with one-bit ADCs**
- **One-bit GAMP outperforms other GAMP variants and LSE**
- **More frames and RF chains enhance estimation performance**

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