The Switching Algorithm to the Preferred Clock Skew Estimator Applicable for the PTP Case in the Generalized fractional Gaussian Noise Environment

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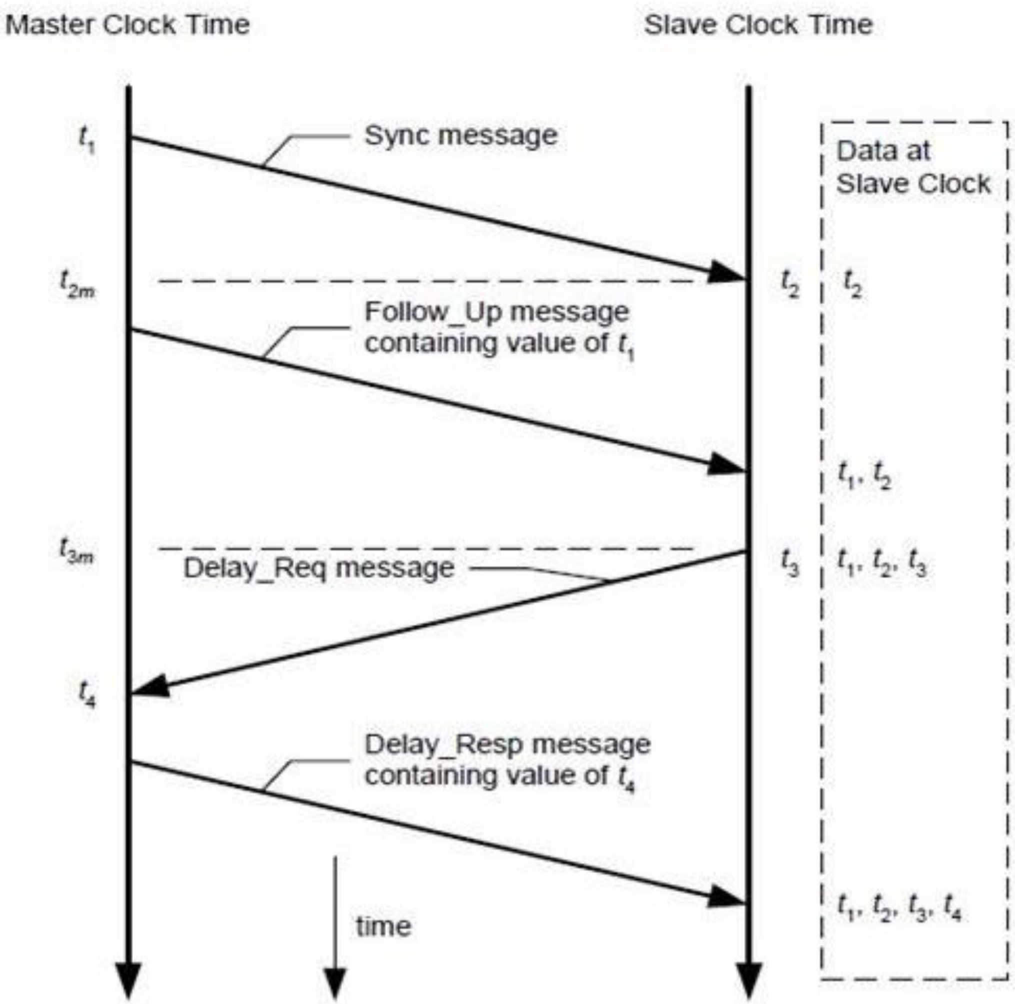
Outline

- Introduction & System Description
- Simulation Results
- Conclusion

Introduction & System Description

- GPS
- NTP
- Synchronous Ethernet
- IEEE1588v2

Introduction & System Description



M. Pinchas, "Cooperative Multi PTP Slaves for Timing Improvement in an fGn Environment," in *IEEE Communications Letters*, vol. 22, no. 7, pp. 1366-1369, July 2018, doi: 10.1109/LCOMM.2018.2830339.

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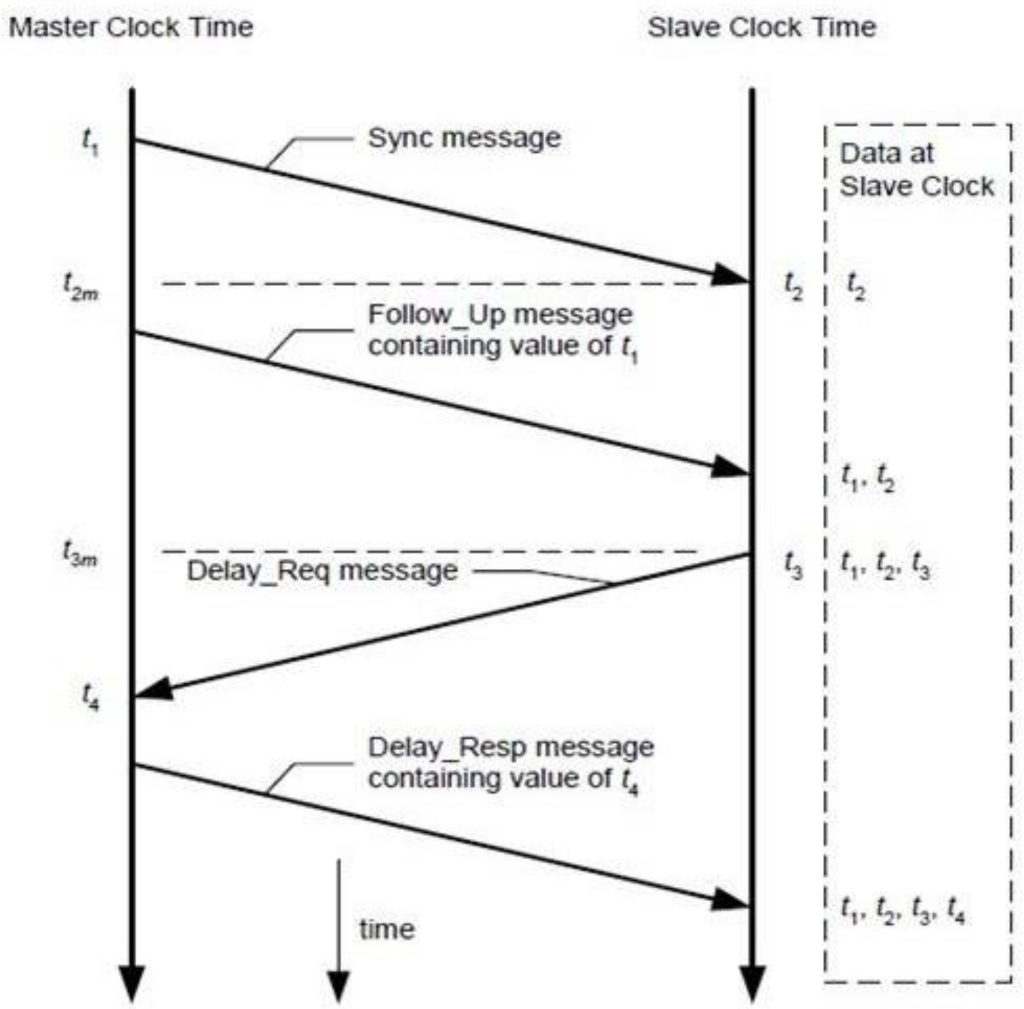

$$t_1[j] + d_{ms} + \omega_1[j] = t_2[j](1+\alpha) + Q$$

$$t_4[j] - d_{sm} - \omega_2[j] = t_3[j](1+\alpha) + Q$$

[1]. Yehonatan Avraham and Monika Pinchas, A Novel Clock Skew Estimator and Its Performance for the IEEE 1588v2 (PTP) Case in Fractional Gaussian Noise/Generalized Fractional Gaussian Noise Environment, Front. Phys., 22 December 2021 Sec. Interdisciplinary Physics Volume 9 - 2021 | https://doi.org/10.3389/fphy.2021.796811

[2]. M. Pinchas, "Cooperative Multi PTP Slaves for Timing Improvement in an fGn Environment," in *IEEE Communications Letters*, vol. 22, no. 7, pp. 1366-1369, July 2018, doi: 10.1109/LCOMM.2018.2830339.

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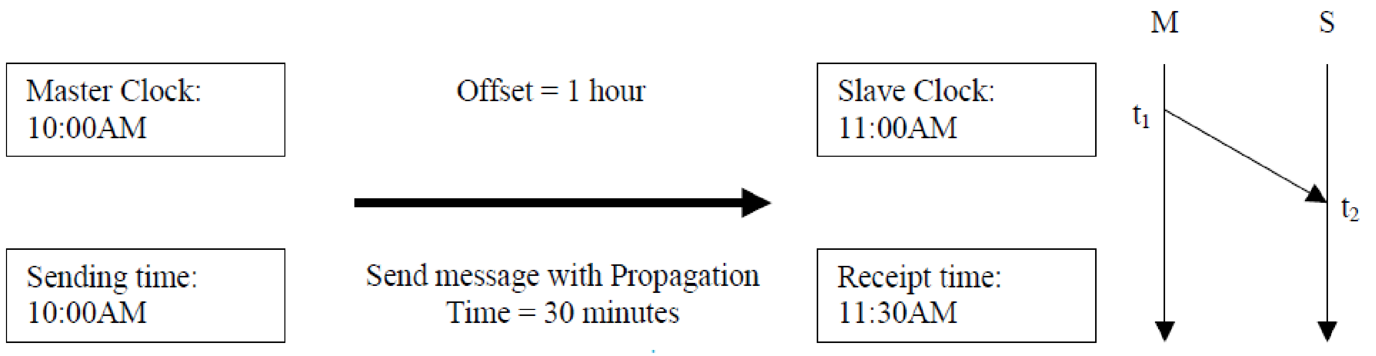

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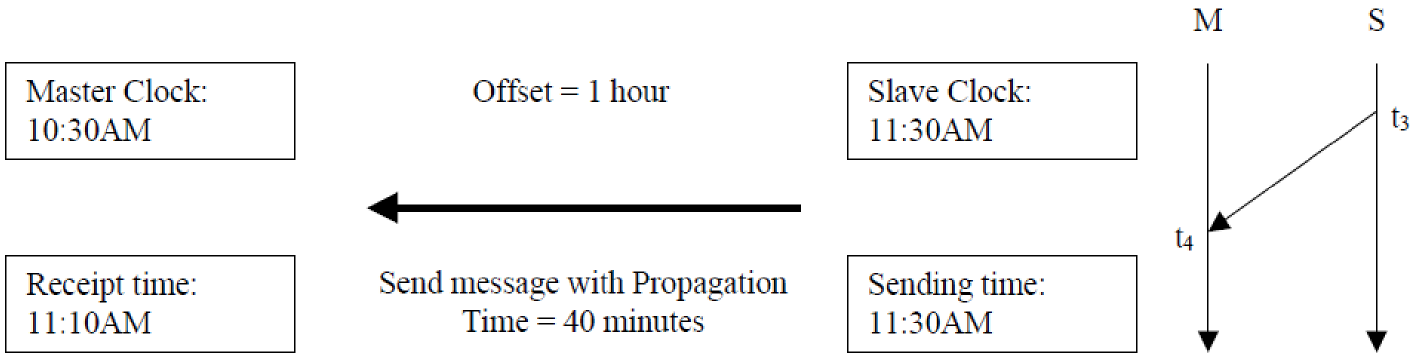
$$t_1[j] + D_{MS} = t_2[j] + Q$$
$$t_4[j] - D_{SM} = t_3[j] + Q$$

$$t_1[j] + t_4[j] = t_2[j] + t_3[j] + 2Q$$

$$Q = \frac{1}{2}((t_4[j] - t_3[j]) - (t_2[j] - t_1[j]))$$

$$t_1[j] - t_4[j] + 2D_{MS} = t_2[j] - t_3[j]$$



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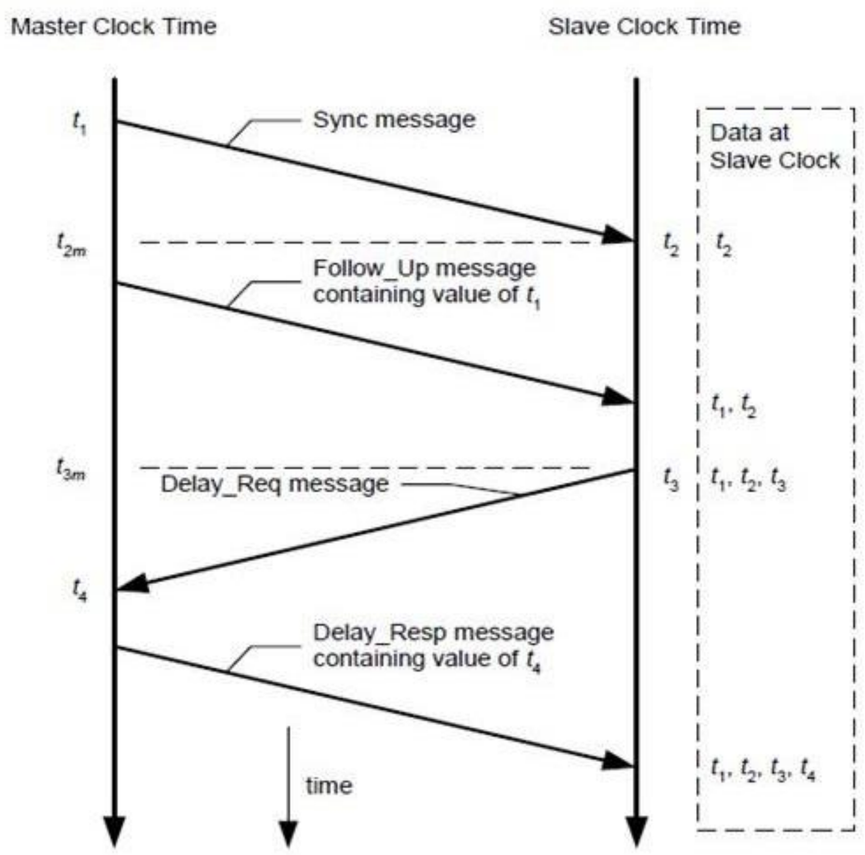
$$D_{MS} = \frac{1}{2}((t_2[j] - t_1[j]) + (t_4[j] - t_3[j]))$$

$$(t_4[j] - t_3[j]) = -20$$
$$(t_2[j] - t_1[j]) = 90$$

$$Q = \frac{1}{2}(-20 - (90)) = -55$$
$$D_{MS} = \frac{1}{2}(90 + (-20)) = 35$$

Introduction & System Description



$$t_1[j] + d_{ms} + \omega_1[j] = t_2[j](1+\alpha) + Q$$

$$t_4[j] - d_{sm} - \omega_2[j] = t_3[j](1+\alpha) + Q$$

We consider three different models for the PDV:

1. The PDV is modeled as a white-Gaussian noise with zero mean and the variance $E[\omega_n[j], \omega_n[m]]$ is $\sigma^2_{\omega_n}$ when $j = m$ and zero when $j \neq m$
   where $E[.]$ denotes the expectation operator on (.) and $n = 1, 2$.
2. The PDV is modeled as an fGn process with zero mean. Based on [Li and Zhao (2013); Peng et al. (2002)] we have:
   a. When $j = m$: $E[\omega_n[j], \omega_n[m]] = \sigma^2_{\omega_n}$.
   b. When $j \neq m$: $E[\omega_n[j], \omega_n[m]] = \frac{\sigma^2_{\omega_n}}{2}\left[\left||j-m|-1\right|^{2H} - 2(|j-m|)^{2H} + (|j-m|+1)^{2H}\right]$.
3. The PDV is modeled as an gfGn process with zero mean. Based on [Li (2021a)] we have:
   a. When $j = m$: $E[\omega_n[j], \omega_n[m]] = \sigma^2_{\omega_n}$.
   b. When $j \neq m$: $E[\omega_n[j], \omega_n[m]] = \frac{\sigma^2_{\omega_n}}{2}\left[\left||(j-m)^a|-1\right|^{2H} - 2|(j-m)^a|^{2H} + (|(j-m)^a|+1)^{2H}\right]$

[1]. Yehonatan Avraham and Monika Pinchas, A Novel Clock Skew Estimator and Its Performance for the IEEE 1588v2 (PTP) Case in Fractional Gaussian Noise/Generalized Fractional Gaussian Noise Environment, Front. Phys., 22 December 2021 Sec. Interdisciplinary Physics Volume 9 - 2021 | https://doi.org/10.3389/fphy.2021.796811

[2]. M. Pinchas, "Cooperative Multi PTP Slaves for Timing Improvement in an fGn Environment," in *IEEE Communications Letters*, vol. 22, no. 7, pp. 1366-1369, July 2018, doi: 10.1109/LCOMM.2018.2830339.

[4]. Li, M. and Zhao, W. (2013). On bandlimitedness and lag-limitedness of fractional gaussian noise. Physica A 392, 1955–1961

[5]. Peng, J., Zhang, L., and Mclernon, D. (2002). Long-range dependence and heavy-tail modeling for teletraffic data. IEEE Signal Processing Magazine 19, 14–27

Introduction & System Description

We consider the following model for the PDV:

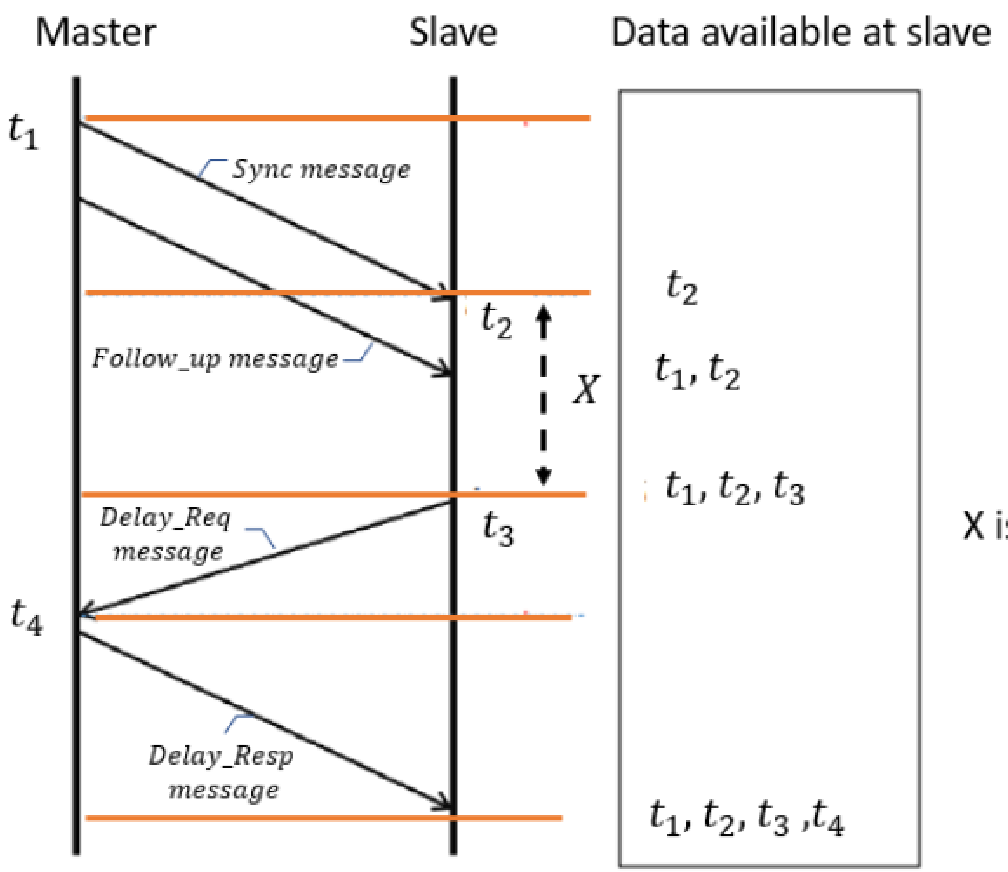
$$E[\omega_n^2] = \frac{\sigma_{\omega_n}^2}{2}\left[\left(\left||(j-i)^{a_p}|-1\right|\right)^{2H_p} - 2(|(j-i)^{a_p}|)^{2H_p} + (|(j-i)^{a_p}|+1)^{2H_p}\right] \;,\; for\; j \neq i$$

$$E[\omega_n^2] = \sigma_{\omega_n}^2 \;,\; for\; j = i \qquad (3)$$

where $n = 1,2$ and $p = F, R$ for the Forward and Reverse paths, respectively. The Hurst exponent parameter (H_p) is in the range of $0.5 \leq H_p < 1$, and the a parameter (a_p) is in the range of $0 < a_p \leq 1$. Please note for $a_p = 1$ we have the fGn case, and for $a_p = 1$ and $H_p = 0.5$ we have the Gaussian case.

M. Li, "Multi-Fractal Traffic and Anomaly Detection in Computer Communications," in CRC Press, Boca Raton, 9 Dec. 2022.
M. Li, "Fractal Teletraffic Modeling and Delay Bounds in ComputerCommunications,"in CRC Press, Boca Raton, 3 May 2022.

Introduction & System Description



$$t_3 = t_2 + X$$

X is predetermined constant time

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The Robust clock skew estimator

$$\hat{\alpha} = \frac{1}{J(J-1)} \sum_{i=1}^{J-1} \sum_{j=1}^{J-i} \left(\frac{T_{1,j}(i) + T_{4,j}(i)}{T_{2,j}(i)} \right) - 1$$

where

$$T_{1,j}(i) = t_1[j+i] - t_1[j], \;\; T_{2,j}(i) = t_2[j+i] - t_2[j], \;\; T_{4,j}(i) = t_4[j+i] - t_4[j]$$

$$\hat{\alpha}_F = \frac{2}{J(J-1)} \sum_{i=1}^{J-1} \sum_{j=1}^{J-i} \left(\frac{T_{1,j}(i)}{T_{2,j}(i)} \right) - 1$$

$$\hat{\alpha}_R = \frac{2}{J(J-1)} \sum_{i=1}^{J-1} \sum_{j=1}^{J-i} \left(\frac{T_{4,j}(i)}{T_{2,j}(i)} \right) - 1$$

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Y. Avraham and M. Pinchas,"Two Novel One-Way Delay Clock Skew Estimators and Their Performances for the Fractional Gaussian Noise/Generalized Fractional Gaussian Noise Environment Applicable for the IEEE 1588v2 (PTP) Case,"Front. Phys. , vol. 10, 2022, https://doi.org/10.3389/fphy.2022.867861

Introduction & System Description

The algorithm	Ref	Forward/ Reverse Paths	PDF models (of the PDV)	Closed Form of the Clock Skew Variance
Linear programming	Puttnies et al. (2018)	Symmetric	Gaussian	No
ML estimator	Chaudhari et al. (2008)	Symmetric	Exponential	No
ML estimator	Li and Jeske (2009)	Symmetric	Exponential	No
ML estimator	Noh et al. (2007)	known	Gaussian/ Exponential	Yes
ML estimator	Noh et al. (2007)	Asymmetric	Gaussian/ Exponential	No
ML estimator	Levy and Pinchas (2015)	Asymmetric	fgn	Yes
KF estimator	Giorgi and Narduzzi (2011)	Asymmetric	Gaussian	-
KF estimator	Chaloupka et al. (2015)	OWD (forward)	-	-
KF & SMC estimator	Shan et al. (2019)	Symmetric	Gaussian	-
SAGE estimator	K.Karthik and S.Blum (2020)	Asymmetric	GMM	No
Our new proposed method		Asymmetric	fGn , gfGn	Yes

Table 1. Clock Skew Estimators

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The Switching Algorithm's Performance

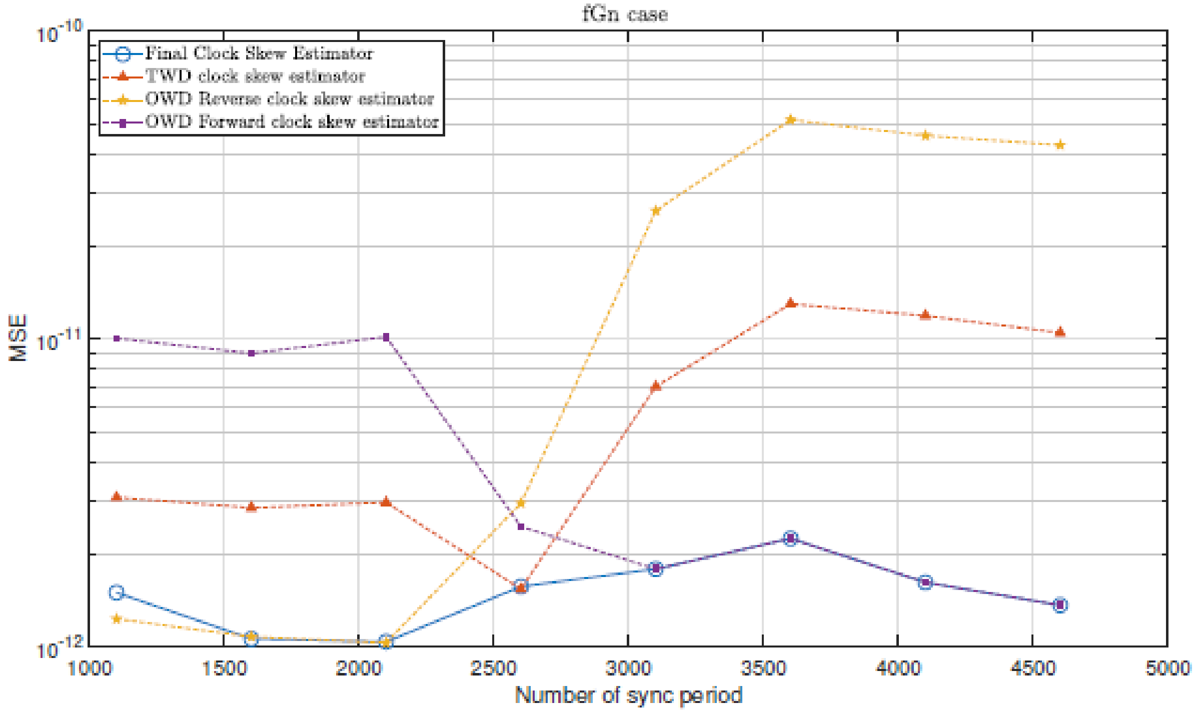

Fig. 5. **case 4**: Performance of the clock skew estimators: (3), (5), (6) and (50). $\alpha = 50ppm$, $Q = 5ms$, $J_o = 400$, for $j \leq 5000$: $\sigma^2_{\omega_1} = 1.96 \cdot 10^{-10}[sec^2]$, for $j \leq 2000$: $\sigma^2_{\omega_2} = 1.96 \cdot 10^{-10}[sec^2]$, for $2000 < j \leq 3000$: $\sigma^2_{\omega_2} = 1.96 \cdot 10^{-10} + 1.166 \cdot 10^{-10}(j - 2000)$, for $j > 3000$: $\sigma^2_{\omega_2} = 1.168 \cdot 10^{-7}[sec^2]$, $\tilde{a} = 0.25$, $H_F = 0.9$, $H_R = 0.5$, MSE$= E[e^2] = 10^{-12}$, $\beta = 0.002$, $\beta_H = 0.002$. The results were obtained for 100 Monte-Carlo trails.

Y. Avraham and M. Pinchas," A Novel Switching Algorithm to the Preferred Clock Skew Estimator Applicable for the PTP Case in the Fractional Gaussian Noise Environment," Mathematical Problems in Engineering, 2023, https://doi.org/10.1155/2023/1695589

Simulation Results

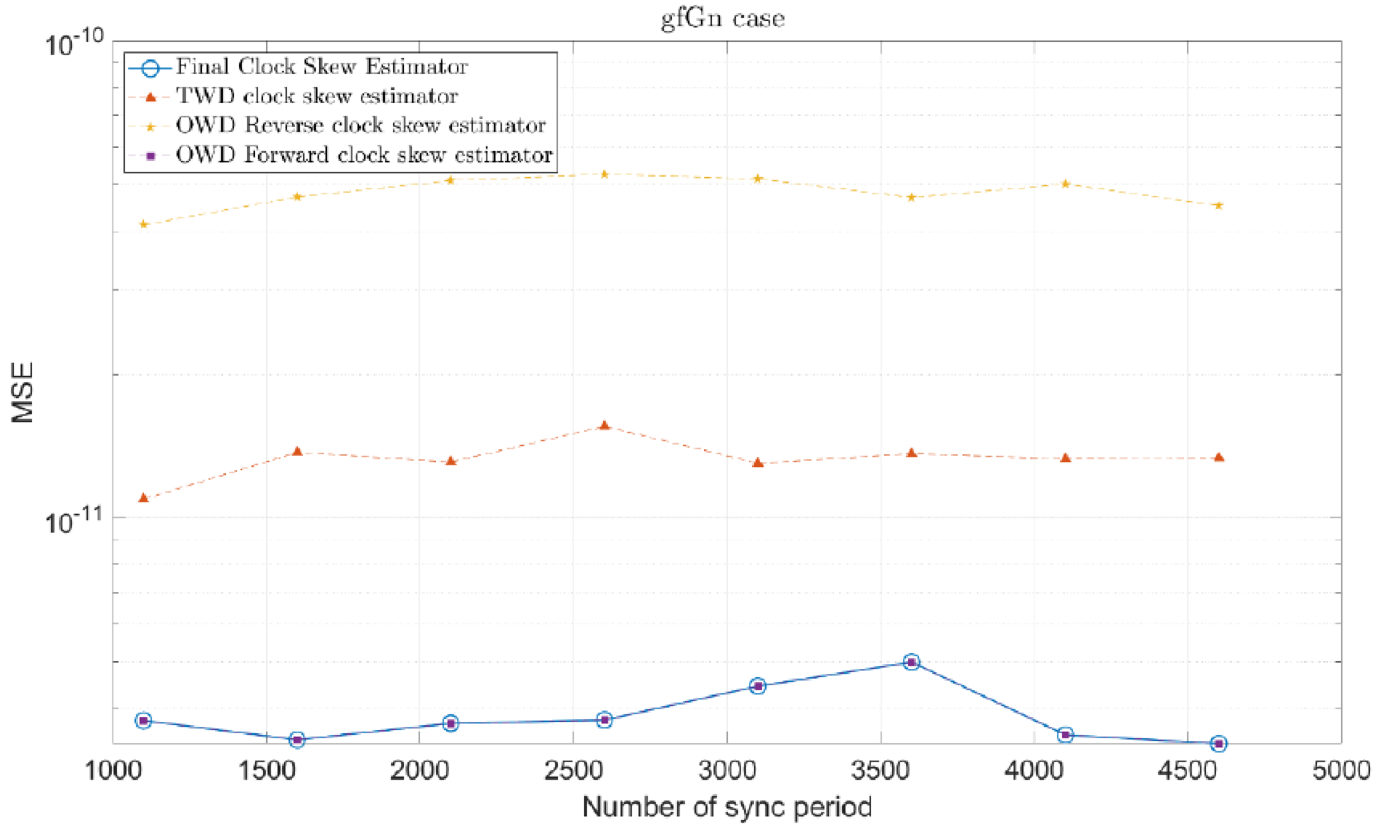

Figure 2. Performance of the clock skew estimators: (4), (5), (6) and the switching algorithm from [13]. $d_{ms} = 0.8m$[sec], $d_{sm} = 0.5m$ [sec], $Q = 5m$[sec], $\sigma_{\omega_1} = 10\mu$, $\sigma_{\omega_2} = 40\mu$, $T_{sync} = 15.6m$[sec] , $H_F = 0.9$, $H_R = 0.9$, $a_F = a_R = 0.08$. The average results were obtained for 100 Monte-Carlo trials.

Simulation Results

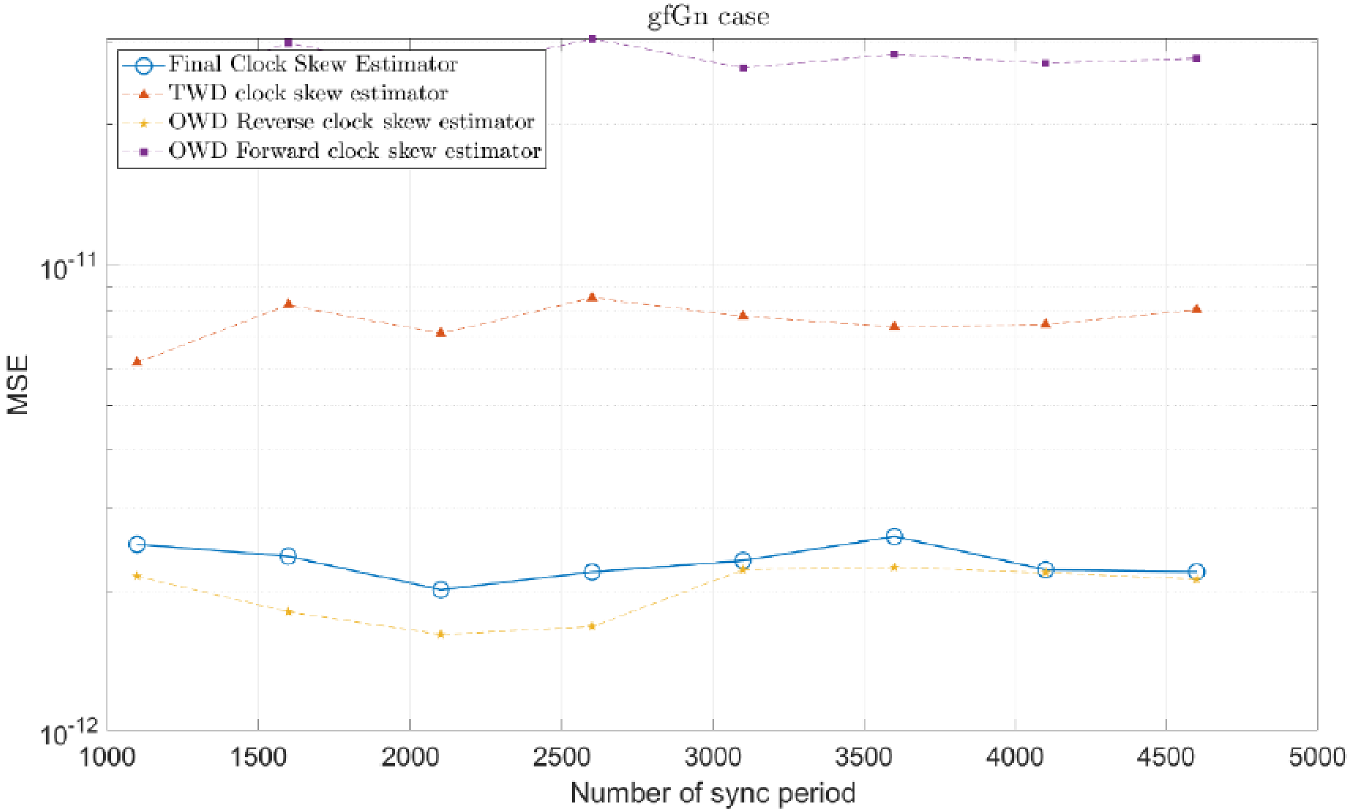

Figure 3. Performance of the clock skew estimators: (4), (5), (6) and the switching algorithm from [13] .$d_{ms} = 0.8m[sec]$, $d_{sm} = 0.5m\ [sec]$, $Q = 5m[sec]$, $\sigma_{\omega_1} = 10\mu$, $\sigma_{\omega_2} = 40\mu$, $T_{sync} = 15.6m[sec]$, $H_F = 0.9$, $H_R = 0.6$, $a_F = 0.08, a_R = 0.04$. The average results were obtained for 100 Monte-Carlo trials.

Simulation Results

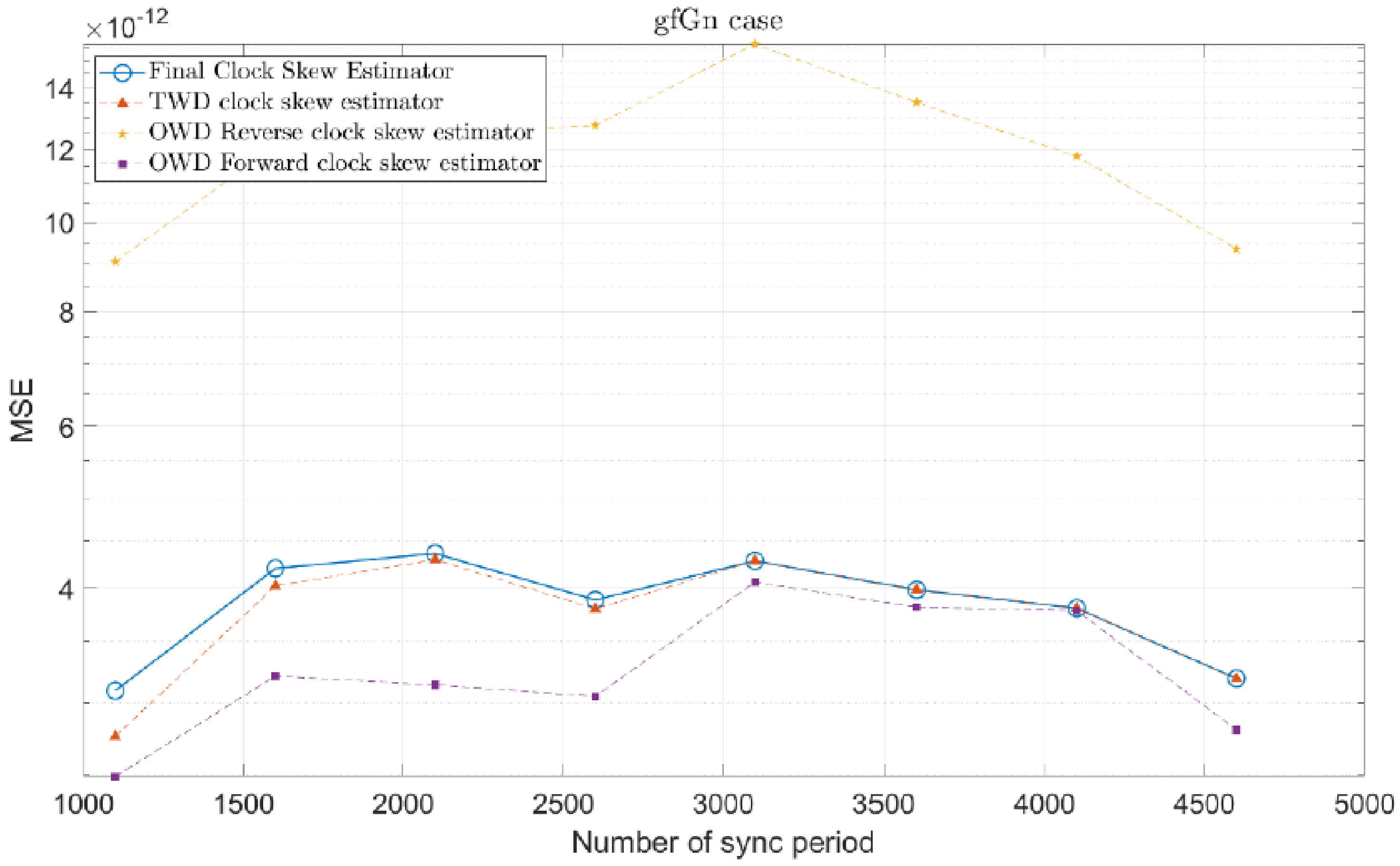

Figure 4. Performance of the clock skew estimators: (4), (5), (6) and the switching algorithm from [13]. $d_{ms} = 0.8m[sec]$, $d_{sm} = 0.5m\ [sec]$, $Q = 5m[sec]$, $\sigma_{\omega_1} = 10\mu$, $\sigma_{\omega_2} = 40\mu$, $T_{sync} = 15.6m[sec]$, $H_F = 0.9$, $H_R = 0.9$, $a_F = 0.8, a_R = 0.08$. The average results were obtained for 100 Monte-Carlo trials.

Simulation Results

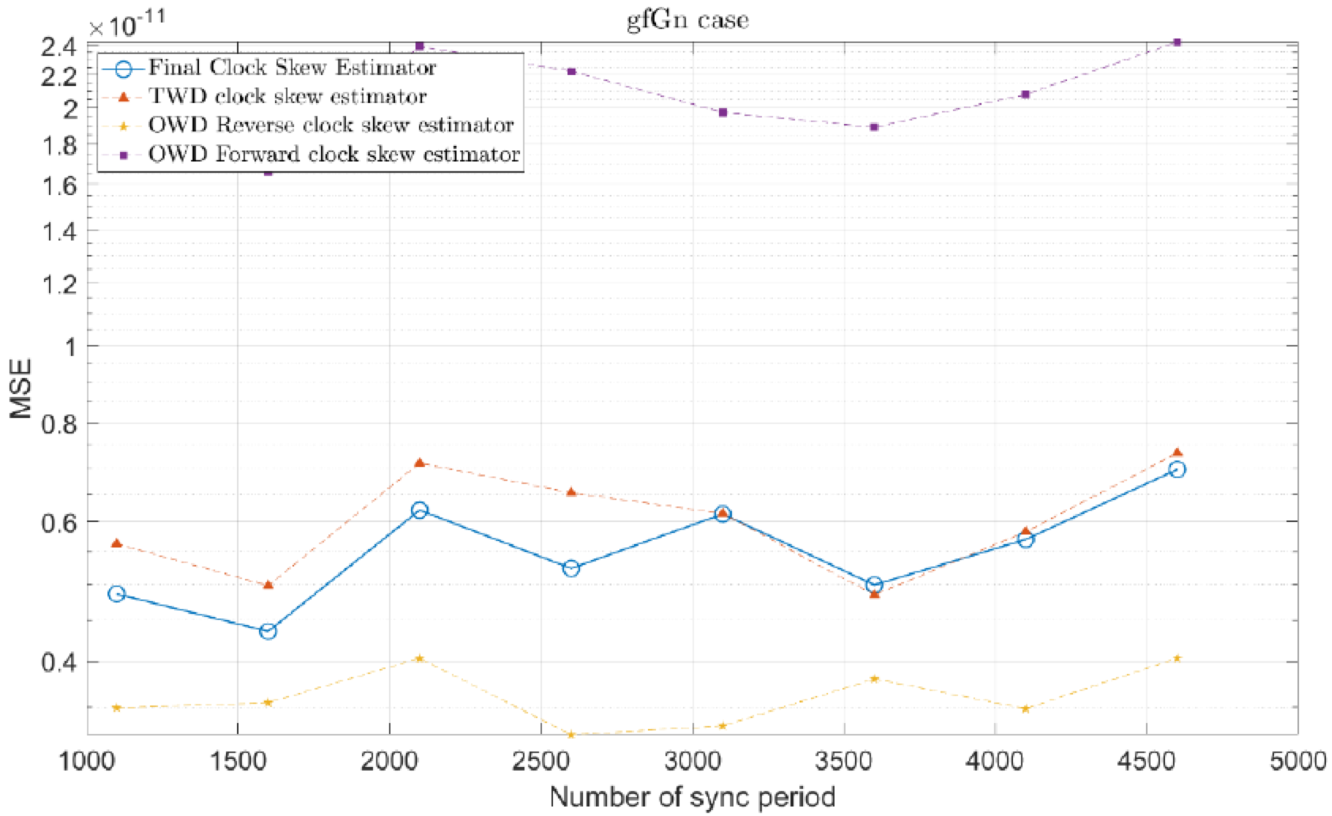

Figure 5. Performance of the clock skew estimators: (4), (5), (6) and the switching algorithm from [13]. $d_{ms} = 0.8m[sec]$, $d_{sm} = 0.5m\ [sec]$, $Q = 5m[sec]$, $\sigma_{\omega_1} = 120\mu$, $\sigma_{\omega_2} = 20\mu$, $T_{sync} = 15.6m[sec]$, $H_F = 0.6$, $H_R = 0.9$, $a_F = 0.08, a_R = 1$. The average results were obtained for 100 Monte-Carlo trials.

Conclusion

- Here, we present the switching algorithm's simulation results for the preferred clock skew estimator appropriate for the PTP scenario in the gfGn environment.
- The gfGn model answers on a wider range of scenarios than the Gaussian cases. This work provides insights concerning the "a" parameter to the PTP clock skew performance obtained by the PTP switching algorithm in the gfGn case.
- In cases where the "a" parameters of the Forward and Reverse path parameters are symmetrical, the fGn case switching algorithm may also answer on the gfGn case.
- In cases where the "a" parameters (of the Forward and Reverse path) are asymmetrical, we may have a degradation in the performance of the switching algorithm. The difference between those "a" parameters affects the switching algorithm performance.
- Future work should estimate the "a" parameters for the Forward and Reverse paths to adapt the switching algorithm to the gfGn environment.

Thank you

Questions?