The Analyses of Handoff-based Travel Speed Estimation Errors

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Abstract

In recent years, cellular network signals have been applied as a powerful tool for traffic information estimation. For instance, the travel speed could be estimated by multiple handoff events based on the distance and time difference between each two handoff events. Therefore, this preprint models the handoff-based travel speed estimation errors, and the errors have been estimated in accordance with the probability model of normal distribution. The mathematical models have been illustrated in this preprint to prove the errors of handoff-based travel speed estimation.

1 Problem Definition

The handoff from Cell $(i-1)$ to Cell (i) is performed by OBU j at location $l_{i,j}$ at time $t_{i,j}$, and another handoff from Cell (i) to Cell $(i+1)$ is performed by OBU j at location $l_{i+1,j}$ at time $t_{i+1,j}$. The time difference between time $t_{i,j}$ and time $t_{i+1,j}$ is assumed as $T_{i,j}$. Therefore, the practical travel distance could be measured as $(l_{i+1,j} - l_{i,j})$, and the practical travel speed $U_{i,j}$ could be measured by Equation (1).

$$U_{i,j} = \frac{(l_{i+1,j} - l_{i,j})}{(t_{i+1,j} - t_{i,j})} = \frac{(l_{i+1,j} - l_{i,j})}{T_{i,j}} \tag{1}$$

The mean location of handoff in the historical dataset from Cell $(i-1)$ to Cell (i) is l_i, and the mean location of handoff in the historical dataset from Cell (i) to Cell $(i+1)$ is l_{i+1}. Therefore, the estimated travel distance could be assumed as $(l_{i+1} - l_i)$, and the estimated travel speed of OBU j $u_{i,j}$ could be calculate by Equation (2).

$$u_{i,j} = \frac{(l_{i+1} - l_i)}{(t_{i+1,j} - t_{i,j})} = \frac{(l_{i+1} - l_i)}{T_{i,j}} \tag{2}$$

The estimated travel distance from location l_i to location l_{i+1} could be assumed as d_i. The estimated handoff location from Cell $(i-1)$ to Cell (i) is $\epsilon_{i,j}$ for OBU j, and The estimated handoff location from Cell (i) to Cell $(i+1)$ is $\epsilon_{i+1,j}$ for OBU j. Therefore, the relationship between the practical travel distance $D_{i,j}$ of OBU j and the estimated travel distance d_i is presented as Equation (3).

$$D_{i,j} = l_{i+1,j} - l_{i,j} = d_i + \epsilon_{i,j} + \epsilon_{i+1,j} \tag{3}$$

The mean squared error (MSE) of the estimated travel distance between location l_i to location l_{i+1} could be calculated by Equation (4).

$$\sum_{j=1}^{n} (D_{i,j} - d_i)^2 = \sum_{j=1}^{n} (\epsilon_{i,j} + \epsilon_{i+1,j})^2 \tag{4}$$

The probability density function (PDF) of location error $\epsilon_{i,j}$ is assumed as $p_i(\epsilon_{i,j})$, and the PDF of location error $\epsilon_{i+1,j}$ is assumed as $p_{i+1}(\epsilon_{i+1,j})$. Therefore, the MSE of the estimated travel distance between location l_i to location l_{i+1} could be calculated by Equation (5).

$$\int_{\epsilon_{i,j}=-\infty}^{\infty} \int_{\epsilon_{i+1,j}=-\infty}^{\infty} (\epsilon_{i,j} + \epsilon_{i+1,j})^2 p_i(\epsilon_{i,j}) p_{i+1}(\epsilon_{i+1,j}) d\epsilon_{i+1,j} d\epsilon_{i,j} \tag{5}$$

2 Handoff-based Travel Distance Estimation Errors

This study assumes that the probability distribution of handoff location errors is a normal distribution.

The PDF of handoff location errors is assumed as the PDF of normal distribution. The PDF of location error $\epsilon_{i,j}$ is assumed as $P_N(\epsilon_{i,j}, \mu_i, \sigma_i)$ with a mean value μ_i and a standard deviation σ_i, and the PDF of location error $\epsilon_{i+1,j}$ is assumed as $P_N(\epsilon_{i+1,j}, \mu_{i+1}, \sigma_{i+1})$ with a mean value μ_{i+1} and a standard deviation σ_{i+1}. Therefore, the MSE of the estimated travel distance between location l_i to location l_{i+1} could be calculated by Equations (6) and (7).

$$P_N(\epsilon, \mu, \sigma) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{\epsilon-\mu}{\sigma}\right)^2} \tag{6}$$

$$\int_{\epsilon_{i,j}=-\infty}^{\infty} \int_{\epsilon_{i+1,j}=-\infty}^{\infty} (\epsilon_{i,j} + \epsilon_{i+1,j})^2 P_N(\epsilon_{i,j}, \mu_i, \sigma_i) P_N(\epsilon_{i+1,j}, \mu_{i+1}, \sigma_{i+1}) d\epsilon_{i+1,j} d\epsilon_{i,j} = (\mu_i + \mu_{i+1})^2 + \sigma_i^2 + \sigma_{i+1}^2 \tag{7}$$