于下降.这是由于当与用户所在NVC查询频率相同的NVC数量*count*不变时,根据算法4,匿名算法需要将这些NVC每隔⌊*count*/*k*⌋个装入一个桶中.随着*k*值增大,每个桶包含的NVC数量将趋于下降,分桶时间降低.

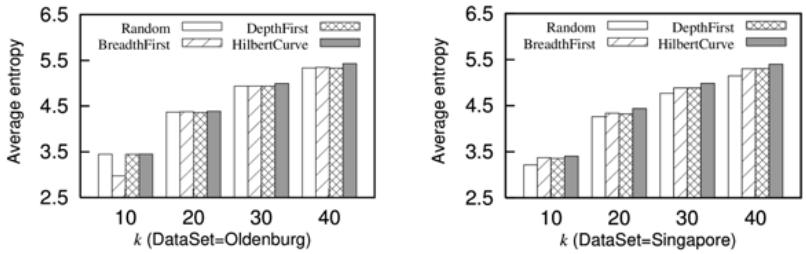

Fig.11 Effect of *k* on entropy

图 11 *k* 值对熵的影响

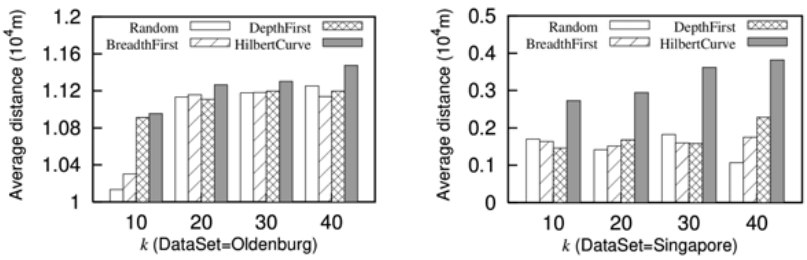

Fig.12 Effect of *k* on average path distance

图 12 *k* 值对平均路径距离的影响

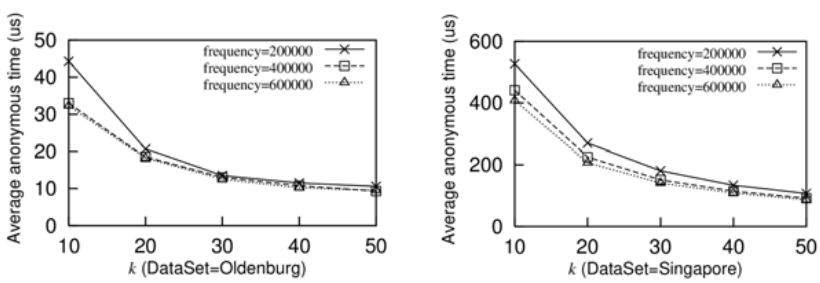

Fig.13 Effect of *k* on average anonymous time

图 13 *k* 值对平均匿名时间的影响

平均查询时间[24]指用户从发起查询到获得查询结果的平均时间.图14反映了在进行200 000次~600 000次NN查询[25]时,平均查询时间随*k*值的变化情况.如图14所示:平均查询时间的变化与平均匿名时间相似,均随着*k*值及查询数量的增大而变小.

K-NN查询[26]旨在查找距离用户最近的*K*个兴趣点,图15反映了在查询频数为200 000次~600 000次的条件下,当用户查询距离其最近的*K*个兴趣点时,平均查询时间随*K*的变化情况.当*K*增大时,由于搜索路径变长,不同查询频数下的平均查询时间都会趋于增加;当*K*取值不变时,平均查询时间随着查询频数的增加而趋于下降,与NN查询的变化趋势一致.

当路网数据庞大、道路繁多时,兴趣点的数量也会大幅增加,对匿名算法的性能要求也会随之提高.图16反映了POI数目对构建NVC(算法1)时间的影响.随着POI数目的增多,构建NVC的时间反而大幅降低.造成这种现象的原因是随着POI数量的增多,顶点到最近POI的路径距离变小,搜索时间变短.

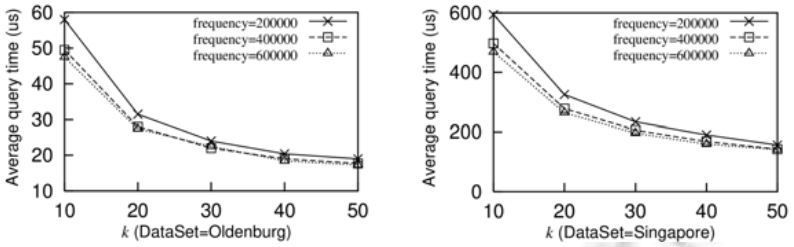

Fig.14 Effect of k on average query time

图 14 k 值对平均查询时间的影响

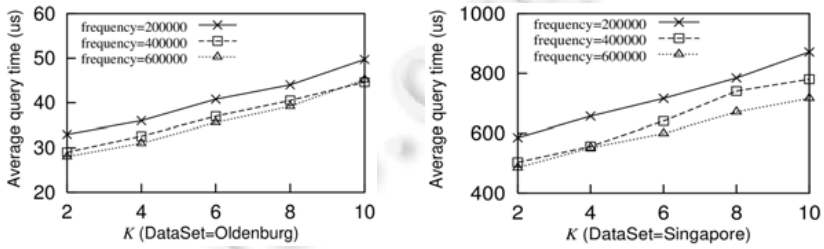

Fig.15 Effect of the number of POIs that users query K on average query time

图 15 用户查询 POI 数 K 对平均查询时间的影响

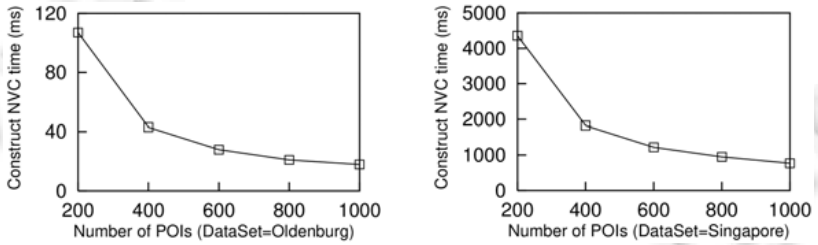

Fig.16 Effect of the number of POIs on the time of constructing each NVC

图 16 兴趣点数量对 NVC 构建时间的影响

图 17 反映了 POI 数目对计算 NVC 的 Hilbert 顺序(算法 2)时间的影响.随着 POI 数目的增加,需要计算的 NVC 相应增加,因此,NVC 的 Hilbert 值的计算时间也呈上升趋势.

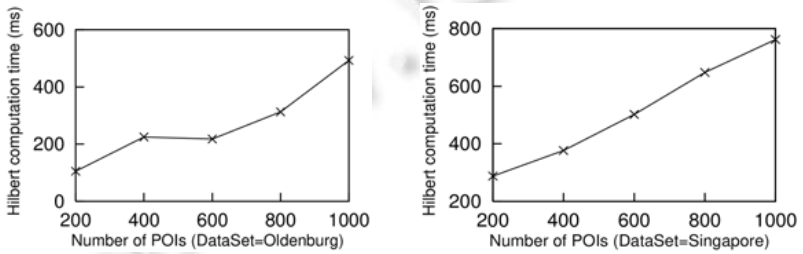

Fig.17 Effect of the number of POIs on the time of constructing the Hilbert value of calculating each NVC

图 17 兴趣点数量对 NVC 的 Hilbert 值的计算时间的影响

图 18 反映了 POI 数目对路段划分(算法 3)时间的影响.随着 POI 数目的增多,路段划分的时间趋于下降,这是因为当兴趣点增多时,每个 NVC 内包含的路段数变少,导致路段划分的基数变小,划分时间变短.

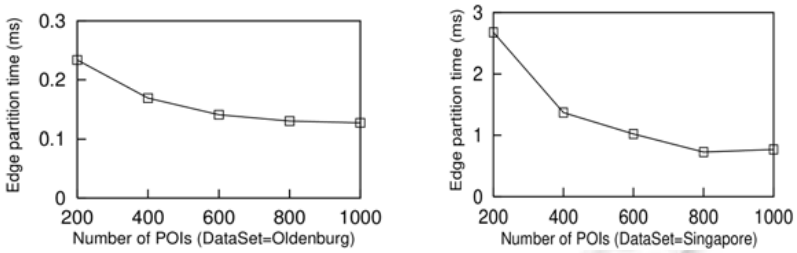

Fig.18 Effect of the number of POIs on the time of edge partition time

图 18 兴趣点数量对路段划分时间的影响

当路网中的 POI 数量增加时,由于 NVC 个数的增加,与用户查询频率相同的 NVC 个数也增加,即:匿名的候选 NVC 个数增加,则导致平均匿名时间趋于增加,如图 19 所示.但值得注意的是:与图 13、图 14 相似,图 20 中随着 POI 数量的增加,平均查询时间的上升趋势与平均匿名时间相似,说明平均查询时间的增加主要源于平均匿名时间,即,POI 数量对查询本身并不产生较大影响.

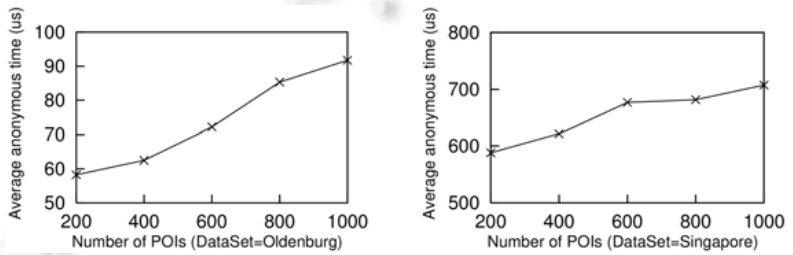

Fig.19 Effect of the number of POIs on the average anonymous time

图 19 兴趣点数量对平均匿名时间的影响

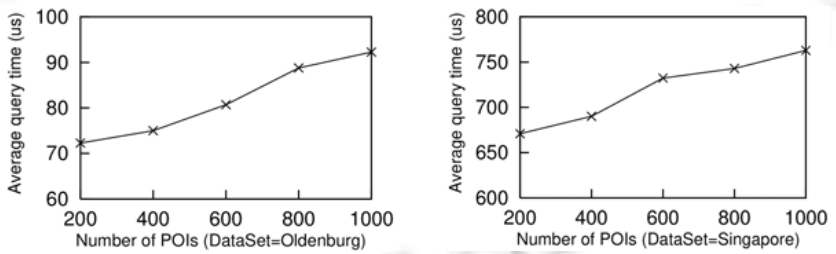

Fig.20 Effect of the number of POIs on the average query time

图 20 兴趣点数量对平均查询时间的影响

由图 16~图 20 可知:在路网复杂、POI 分布密集的情况下,本文匿名算法也能表现出良好的拓展性.根据算法在两个数据集上的表现可以得出结论:在稀疏和稠密的路网环境下,本文提出的方法都能表现出良好的性能.

7 结束语

本文提出了一种针对路网环境下兴趣点查询的隐私保护方法,该方法充分考虑到路网的历史查询频率以及匿名路段之间的相互性问题,使得生成的假位置频率相近、位置分散,能够抵御重放攻击和推断攻击.本文提出的假位置生成算法在熵值、方差、平均路径距离上都具有显著优势,因此,本文提出的位置匿名算法可以有效保护用户的位置隐私.实验结果表明:本文方法具有良好的扩展性,能够在不影响服务质量的前提下保护用户的位置隐私,对路网环境下进行兴趣点查询的位置隐私保护领域具有广泛而深远的现实意义.

当然,路网环境下的位置隐私保护领域还有许多其他问题有待深入探索和解决.在未来的工作中,我们将向两个方向进行拓展:(1) 进一步提高算法的性能,使其能够提供更高效便捷的隐私保护服务;(2) 研究更优的隐

私保护方法,将其应用到更广泛的位置服务领域,不局限于路网上的兴趣点查询范围.

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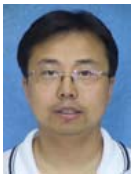

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