













节点场景进行仿真实验,进行至 400min 时,计算该时间段内的整网连通度,移除 Ferry 节点  $F_a$ ,按图 5 中(b)3 个 Ferry 节点场景继续实验至 800min,计算最近 400min 内的整网连通度,移除 Ferry 节点  $F_c$ 后再按图 5 中(c)2 个 Ferry 节点场景继续实验至 1 200min,计算最近 400min 内的整网连通度.详细的实验参数设置见表 4.

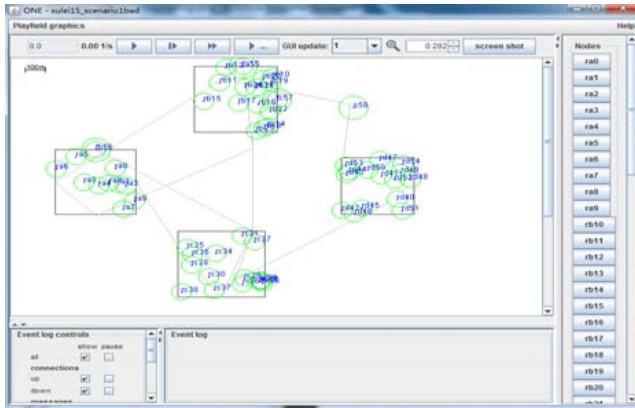
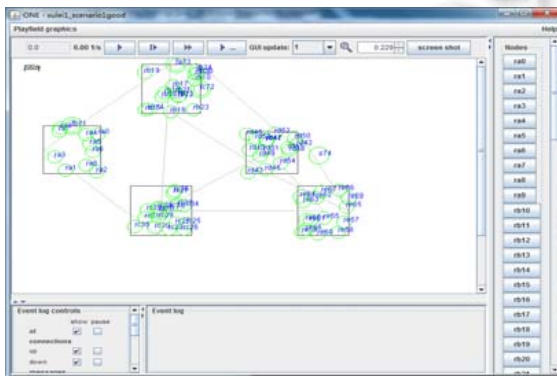


Fig.4 Experimental Scenario 1  
图 4 实验场景 1

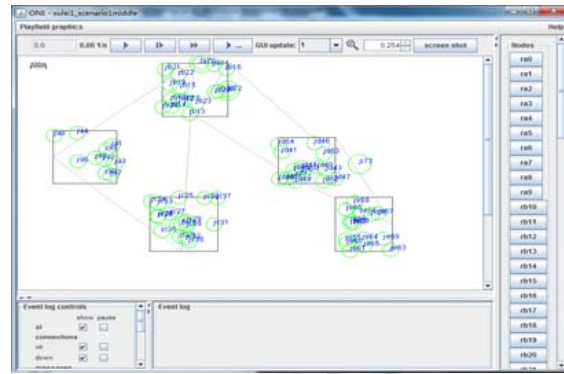
Table 3 Experimental parameters  
(experimental Scenario 1)

表 3 主要实验参数(实验场景 1)

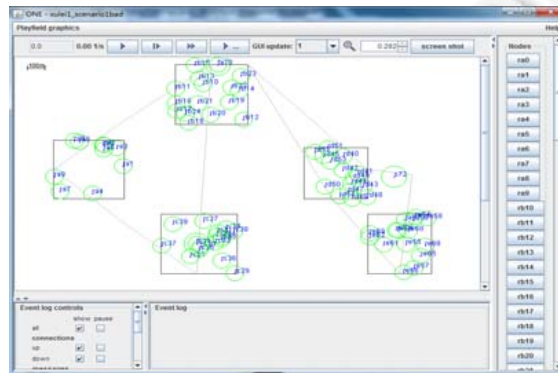
仿真参数	值
实验时长(h)	12
区域面积(m×m)	335×330,860×870, 220×190,1035×1050
区域节点数(个)	10,15,15,15
Ferry 节点通信半径(m)	30,50,70
消息产生间隔(s)	20
$F_a$ 速度范围(m/s)	1.5-2,3-5,5-10
$F_b$ 速度范围(m/s)	1.5-3,4-6,6-9
$F_c$ 速度范围(m/s)	1-2,5-6,7-9
TTL(s)	1 200



(a) 4 个 Ferry 节点



(b) 3 个 Ferry 节点



(c) 2 个 Ferry 节点

Fig.5 Experimental Scenario 2

图 5 实验场景 2

**Table 4** Experimental parameters (experimental Scenario 2)

**表 4** 主要实验参数(实验场景 2)

仿真参数	值
实验时长(h)	12
区域面积(m×m)	400×395,410×400,430×400,360×345,360×400
区域节点数(个)	10,15,15,15,15
Ferry 节点通信半径(m)	30,50,70
消息产生间隔(s)	20
$F_a$ 速度范围(m/s)	8-10
$F_b$ 速度范围(m/s)	8-10
$F_c$ 速度范围(m/s)	8-10
$F_d$ 速度范围(m/s)	8-10
TTL(s)	1 200

**4.2 实验分析**

对于 OSNs 而言,并没有评估连通性模型的标准,此前对连通度模型研究中通常采用消息投递成功率或投递时延作为衡量网络连通度的参考,因此本文中采用消息投递成功率作为模型的对比来验证模型的有效性。

保持 Ferry 节点个数不变,改变 Ferry 节点速度,将实验场景 1 数据导入 Matlab 工具计算出整网连通度和消息投递成功率.结果如图 6 和图 7 所示。

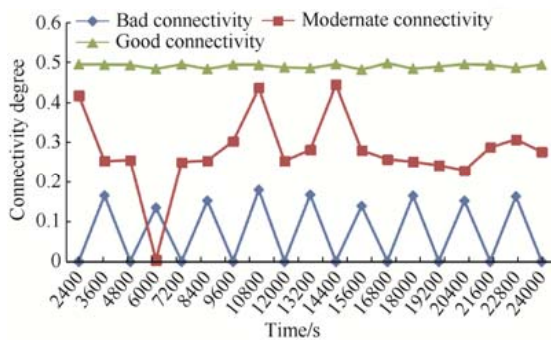


Fig.6 Line graph of network connectivity changes over time (Ferry node speed change)

图 6 整网连通度随时间变化折线图 (Ferry 节点速度改变)

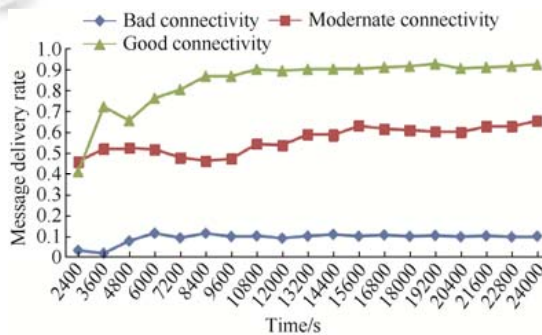


Fig.7 Line graph of message delivery success rate changes over time (Ferry node speed change)

图 7 消息投递成功率随时间变化折线图 (Ferry 节点速度改变)

从图 6 可以看出,网络连通度值的区间为 0-0.6,随着 Ferry 节点速度的加快,整网连通度也随之提升,且相同速度下,整网连通度值波动不大,不同速度下,整网连通度值在图中表现出层次关系.从图 7 可以看出,消息投递成功率随着 Ferry 节点速度的下降而变小,与整网连通度类似,在不同速度下,消息投递成功率呈现出层次关系.对比图 6 和图 7,可以看出,由定义(5)计算得到的整网连通度不仅可以从整体上反映整网连通性的变化情况,并且连通度变化趋势与消息成功投递概率基本吻合。

保持 Ferry 节点速度不变,改变 Ferry 节点个数,计算实验场景 2 的实验数据,可以得到改变 Ferry 节点个数后,整网连通度和消息投递成功率的变化曲线如图 8、图 9 所示。

从图 8 和图 9 可以看出,移除  $F_d$  后,整网连通度并未发生很大的改变,消息投递成功率因为  $F_d$  的移除有所下降,但下降幅度不大.此时,整网连通度和消息投递成功率的曲线近似相同.移除  $F_c$  后,网络的连通性发生较大的变化,整网连通度和消息投递成功率有了明显的下降,两者在数值上都能良好地体现出网络的变化情况.对比图 8 和图 9,可以看出,整网连通度变化趋势与消息投递成功率基本吻合.因此本文构建的整网连通度模型能够很好地反映连通性变化的差异,也能较好地反映网络的连通程度。



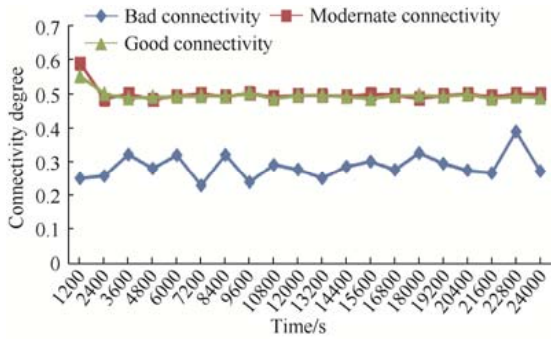


Fig.8 Line graph of network connectivity changes over time (Ferry node number changes)

图 8 整网连通度随时间变化折线图 (Ferry 节点个数改变)

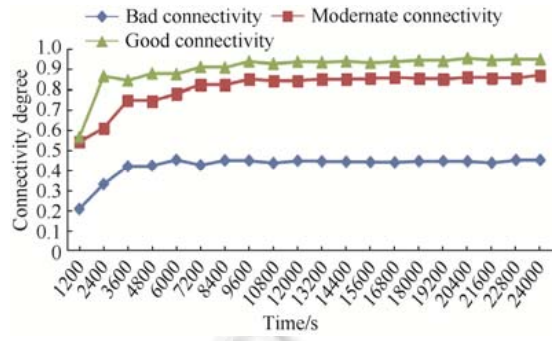


Fig.9 Line graph of message delivery success rate changes over time (Ferry node number changes)

图 9 消息投递成功率随时间变化折线图 (Ferry 节点个数改变)

为了进一步验证模型性能,本文将文献[24]中实验数据导入整网连通度模型,对比分析本文构建的整网连通度模型与基于 Katz 中心性网络连通度模型的优劣,计算得到整网连通度与消息投递成功率如图 10~图 12 所示.

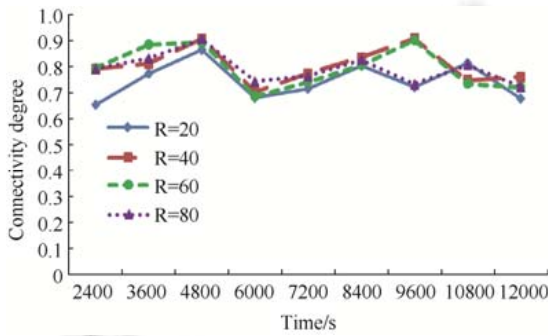


Fig.10 Line graph of network connectivity changes over time based on Katz

图 10 基于 Katz 中心性的网络连通度随时间变化折线图

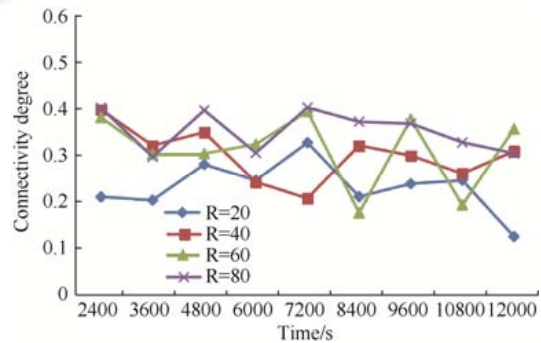


Fig.11 Line graph of network connectivity changes over time

图 11 整网连通度随时间变化折线图

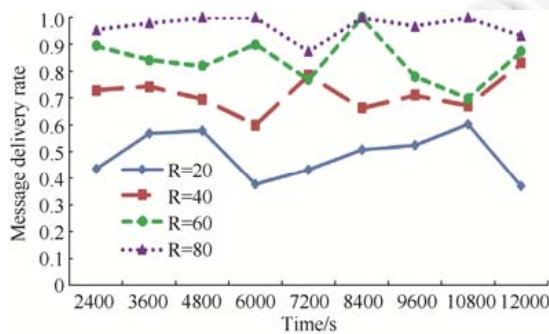


Fig.12 Line graph of message delivery success rate changes over time

图 12 消息投递成功率随时间变化折线图

对比图 10~图 12,可以看出,本文构建的整网连通度模型与基于 Katz 中心性的网络连通度模型均能反映网络连通度的真实情况.但是,当随着区域节点通信半径 R 的变小,网络连通性变差时,基于 Katz 中心性的网络连通

度模型并未出现明显变化,而本文构建的连通度模型能够更好地体现出网络的变化和反映网络连通性的波动情况,为了更好地体现出本文构建的整网连通度模型与基于 Katz 中心性的网络连通度模型对网络连通性发生变化时的区分程度,本文通过计算不同通信半径场景之间差值的方差来衡量模型对网络连通度变化的区分程度,计算结果见表 5.由表 5 可以看出,在不同通信半径场景中,本文构建的整网连通度模型的连通度差值的方差大于基于 Katz 中心性的网络连通度模型,且更接近与消息投递成功率的差值.所以与基于 Katz 中心性的网络连通度模型相比,本文构建的整网连通度模型对不同连通度网络的区分更明显.因此,当网络连通性发生变化时,本文构建的连通度模型的灵敏度更高,且整网连通度曲线与消息投递成功率曲线吻合程度更高.因此,相对于 Katz 中心性连通度模型,本模型更适用于网络拓扑频繁变化的场景.

Table 5 Variance of difference

表 5 差值的方差

模型/消息投递成功率	R=80 与 R=60	R=60 与 R=40	R=40 与 R=20
基于 Katz 中心性的网络连通度	0.005 059 258	0.001 112 711	0.005 278 319
整网连通度	0.006 772 027	0.009 714 63	0.009 456 855
消息投递成功率	0.007 944 742	0.014 619 515	0.015 232 003

## 5 结束语

本文研究多区域 OSNs 的连通性问题.不同场景下的仿真实验结果表明,构建的整网连通度模型与实际的消息投递成功率吻合程度较高,能够较好地反应网络连通度的变化情况.本文的主要贡献如下.

1) 针对 OSNs 机会性、动态性的特点,将网络划分为一系列快照,获得其拓扑信息,采用时空图构建 OSNs 的时空图模型.

2) OSNs 中,区域内感知消息依靠 Ferry 节点投递至 Sink 节点.根据消息的可达性,综合考虑了消息传输过程的时间和空间特性,定义 OSNs 的连通性指标为时间距离和拓扑距离,结合网络快照间的时间距离和拓扑距离构建了整网连通度模型.

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